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Thos. Shipley

PRESIDENT 1912

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TRANSACTIONS

OF

THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

VOL. [illegible]

Eighth Annual Meeting, New York, N. Y.

December 2 and 3,

1912

PUBLISHED BY THE SOCIETY
FROM ITS OFFICES, NO. 154 NASSAU STREET
NEW YORK, N. Y.

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Thos. Shipley

PRESIDENT 1912

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OF

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VOLUME IX

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PRESIDENT 1912

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Mar. 3, 1914
HARVARD UNIVERSITY
SCHOOL OF ENGINEERING

Jul. 1, 1919
Transferred to
Harvard College Library

Organized December 5, 1904, at New York, N. Y.

Incorporated under the Laws of the State of New York,
August 30, 1905.

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OFFICERS

OF

THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

1911-1912

PRESIDENT

THOMAS SHIPLEY.....York, Pa.

VICE-PRESIDENTS

ALBERT RUEMMELI.....St. Louis, Mo.

Term expired at Annual Meeting of 1912

HENRY TORRANCE, JR.....New York, N. Y.

Term expires at Annual Meeting of 1913

DIRECTORS

CARL BEHN.....New York, N. Y.
CHARLES DICKERMAN.....Philadelphia, Pa.
GARDNER T. VOORHEES.....New York. N. Y.

Terms expired at Annual Meeting of 1912

LOUIS BLOCK.....New York, N. Y.
LOUIS DOELLING.....New York, N. Y.
EDWARD N. FRIEDMANN.....New York, N. Y.

Terms expire at Annual Meeting of 1913

VICTOR H. BECKER.....Chicago, Ill.
CHARLES L. CASE.....Boston, Mass.
THEODORE O. VILTER.....Milwaukee, Wis.

Terms expire at Annual Meeting of 1914

TREASURER

FRANK A. HORNE.....New York, N. Y.

SECRETARY

WILLIAM H. ROSS.....New York, N. Y.

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PAST AND PRESENT OFFICERS

PRESIDENTS.

John E. Starr—1905.....New York, N. Y.
W. Everett Parsons—1906.....Newark, N. J.
D. S. Jacobus—1907.....Hoboken, N. J.
Edgar Penney—1908.....Newburgh, N. Y.
Louis Block—1909.....New York, N. Y.
Roderick H. Tait—1910.....St. Louis, Mo.
Edward N. Friedmann—1911.....New York, N. Y.
Thomas Shipley—1912.....York, Pa.

VICE-PRESIDENTS.

H. B. Roelker—1905.....New York, N. Y
P. De C. Ball—1905-1906.....St. Louis, Mo.
John E. Starr—1906-1907.....New York, N. Y.
James Wills[1]—1907-1908.....New York, N. Y.
Karl E. Vesterdahl—1908-1909.....New York, N. Y.
Homer McDaniel—1909-1910.....Cleveland, Ohio
Chares E. Lucke—1910-1911.....New York, N. Y.
Albert Ruemmeli—1911-1912.....St. Louis, Mo.
Henry Torrance, Jr.—1912-1913.....New York, N. Y.

TREASURERS.

Walter C. Reid—1905-1911.....New York, N. Y.
Frank A. Horne—1912.....New York, N. Y.

SECRETARY.

William H. Ross—1905-1912.....New York, N. Y.

DIRECTORS.

Louis Block—1905-1908 and 1911-1913.....New York, N. Y.
W. Everett Parsons—1905.....Newark, N. J.
Edgar Penney—1905-1907.....Newburgh, N. Y.
D. S. Jacobus—1905-1906.....Hoboken, N. J.
E. L. Phillips—1905-1906.....New York, N. Y.
W. T. Robinson—1905-1906.....Philadelphia, Pa.
L. Howard Jenks—1905-1907.....New York, N. Y.
Thomas Shipley—1905-1911.....York, Pa.
Henry Torrance, Jr.—1905-1907.....New York, N. Y.
H. B. Roelker—1906-1908.....New York, N. Y.
J. J. de Kinder—1907-1909.....Philadelphia, Pa.
F. W. Pilsbry—1907-1909.....Chicago, Ill.
Llewellyn Williams—1907-1909.....Boston, Mass.
John E. Starr[2]—1908.....New York, N. Y.
John C. Wait—1908-1910.....New York, N. Y.

[1] Deceased.
[2] Filled the unexpired term, 1908, of Edgar Penney.

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DIRECTORS—Continued

KARL WEGEMANN—1908-1910.....New York, N. Y.
MADISON COOPER—1909-1911.....Watertown, N. Y.
N. H. HILLER—1909-1911.....Carbondale, Pa.
W. H. MANNS—1909-1911.....Waynesboro, Pa.
CHARLES DICKERMAN—1910-1912.....Philadelphia, Pa.
EDWARD N. FRIEDMANN[3]—1910 and 1912-1913.....New York, N. Y.
GARDNER T. VOORHEES—1910-1912.....New York, N. Y.
CARL BEHN[4]—1911-1912.....New York, N. Y.
LOUIS DOELLING—1911-1913.....New York, N. Y.
VICTOR H. BECKER[5]—1912-1914.....Chicago, Ill.
CHARLES L. CASE—1912-1914.....Boston, Mass.
THEODORE O. VILTER—1912-1914.....Milwaukee, Wis.

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[3] Filled the unexpired term, 1912-1913, of Thomas Shipley.
[4] Filled the unexpired term, 1911-1912, of Edward N. Friedmann.
[5] Deceased.

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THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS.

CONSTITUTION.

NAME, OBJECT AND GOVERNMENT.

C 1. The title of this Society shall be "The American Society of Refrigerating Engineers."

C 2. The object of this Society is to promote the Arts and Sciences connected with Refrigerating Engineering.

C 3. The principal means for this purpose shall be the holding of meetings for the reading and discussion of appropriate papers, and for social intercourse; the publication and distribution of its papers and discussions; and the maintenance of a library of data on refrigeration.

C 4. The Society shall be governed by this Constitution, and by By-Laws and Rules in harmony therewith.

C 5. The Society shall be organized as a Corporation under the Laws of the State of New York.

MEMBERSHIP.

C 6. Persons connected with the Arts and Sciences relating to Refrigerating Engineering may be eligible for admission into the Society.

C 7. The membership of the Society shall consist of Members, Associates and Juniors. Members and Associates are entitled to vote and to hold office. Juniors shall not be entitled to vote nor to be officers of the Society, but shall be entitled to the other privileges of membership.

C 8. Members and Associates are entitled to vote on all questions before any meeting of the Society in person, or by proxy given to a voting member in writing. A proxy shall not be valid for a greater time than six months.

C 9. A Member shall be twenty-six years of age or over. He must have been so connected with Refrigerating Engineering as to be competent as a designer or as a constructor, to take responsible charge of work in his branch of Refrigerating Engineering, or he must have served as a teacher of Refrigerating Engineering for more than five years.

C 10. An Associate shall be twenty-six years of age or over and shall be so connected with Refrigerating Engineering as to be competent to take charge of engineering work, or to co-operate with Refrigerating Engineers.

C 11. A Junior shall be twenty-one years of age or over. He must have had such Refrigerating Engineering experience as will enable him to fill a responsible subordinate position in Refrigerating Engineering work, or he must be a graduate of an engineering school.

C 12. The rights and privileges of every Member, Associate and Junior shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

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ADMISSION.

C 13. All applications for membership as Member, Associate or Junior shall be presented to the Council, which shall consider and act upon each application, assigning each approved applicant to the classification to which, in the judgment of the Council, he is entitled. The name of each candidate thus approved by the Council shall, unless objection is made by the applicant, be submitted to the voting membership for election by means of a letter ballot.

C 14. Associates or Juniors desiring to change their grade of membership shall make application to the Council in the same manner as is required in the case of a new applicant.

C 15. Election to membership shall be by a sealed letter ballot as the By-Laws shall provide. Adverse votes to the number of four per cent. of the votes cast shall be required to defeat the election of an applicant.

C 16. Each person elected shall subscribe to this Constitution, and shall pay the initiation fee before he can be entitled to the rights and privileges of membership. If such person does not comply with these requirements within six months after notice of his election, he will be deemed to have declined election. The Council may, thereupon, declare his election void.

INITIATION FEES AND DUES.

C 17. The initiation fee for membership shall be as follows:

For Members and Associates, five dollars.

For Juniors, five dollars. A Junior, on promotion to any other grade of membership, shall pay an additional fee of five dollars.

The annual dues for membership shall be as follows:

For Members and Associates, ten dollars.

For Juniors, five dollars for the first six years of their membership, and thereafter the same as for a Member or Associate.

SUSPENSIONS AND EXPULSIONS.

C 18. Any Member, Associate or Junior who shall leave his annual dues unpaid for two years shall, at the discretion of the Council, have his name stricken from the roll of membership and shall cease to have any further rights of membership.

C 19. The Council may refuse to receive the dues of any Member, Associate or Junior who shall have been adjudged by the Council to have violated the Constitution or By-Laws of the Society, or who, in the opinion of the Council, expressed by a two-thirds vote of the entire Council, shall have been guilty of conduct rendering him unfit to continue in its membership; and the Council may expel such person and remove his name from the list of members.

THE COUNCIL.

C 20. The affairs of the Society shall be managed by a Board of Directors chosen from among its Members and Associates, which shall be styled "The Council." The Council shall consist of the President of the Society, who shall be the presiding officer; the two Vice-Presidents, Treasurer and fifteen Members or Associates. Seven Members of the Council shall constitute a

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quorum for the transaction of business. The Secretary may take part in the deliberations of the Council, but shall not have a vote therein.

C 21. The Council thus constituted shall regulate its own proceedings and shall be the legal Trustee of the Society. All gifts or bequests not designated for a specific purpose shall be invested by the Council and only the income therefrom may be used for current expenses.

C 22. Should a vacancy occur in the Council, or in any elective office except the presidency, through death, resignation or other cause, the Council may elect a Member or Associate to fill the vacancy until the next annual election.

C 23. The Council shall present at the Annual Meeting of the Society a report verified by the President or Treasurer or by a majority of the members of the Council, showing the whole amount of real and personal property owned by the Society, where located, and where and how invested, and the amount and nature of the property acquired during the year immediately preceding the date of the report, and the manner of the acquisition; the amount applied, appropriated or expended during the year immediately preceding such date, and the purposes, objects or persons to or for which such applications, appropriations or expenditures have been made; also the names and places of residence of the persons who have been admitted to membership in the Society during the last year, which report shall be filed with the records of the Society, and an abstract thereof shall be entered in the minutes of the proceedings of the Annual Meeting.

C 24. An act of the Council which shall have received the expressed or the implied sanction of the membership at the next subsequent meeting of the Society shall be deemed to be the act of the Society, and shall not afterward be impeached by any member.

C 25. The Council may, by a two-thirds vote of the members present, declare any elective office vacant, on the failure of its incumbent for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office, and shall thereupon appoint a Member or Associate to fill the vacancy until the next Annual Meeting. The said appointment shall not render the appointee ineligible to election to any office.

OFFICERS.

C 26. At each Annual Meeting there shall be elected from among the Members and Associates:

A President to hold office for one year.

Two Vice-Presidents, one to hold office for one year, and one to hold office for two years. After the first year one Vice-President to be elected annually for a term of two years.

A Treasurer to hold office for one year.

Fifteen Members or Associates shall be members of the Council, five being elected each year, and each to hold office for three years, with the exceptions contained in this paragraph. On the year of acceptance of this amendment (1912), and in order to increase the number of Directors from nine, as heretofore, to fifteen, as provided in this paragraph and in amended Section C 20, nine Members or Associates shall be elected to the Council, five to hold office

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for three years, two to hold office for two years, and two to hold office for one year, thereafter five Members or Associates shall be elected each year.

C 27. The election of officers shall be by ballot, as the By-Laws shall provide.

C 28. The term of all elective officers shall begin on the adjournment of the Annual Meeting of the Society. Officers shall continue in their respective offices until their successors have been installed.

C 29. A President or Vice-President shall not be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

C 30. The Council, at its first meeting after the Annual Meeting of the Society, shall appoint a Member or Associate to serve as Secretary of the Society subject to the pleasure of the Council. The Secretary shall receive a salary which shall be fixed by the Council at the time of his appointment.

C 31. The President, Secretary and Treasurer shall perform the duties legally or customarily attaching to their respective offices under the laws of the State of New York, and such other duties as may be required of them by the Council.

C 32. A vacancy in the office of President shall be filled by the Vice-President who is senior by age.

MEETINGS.

C 33. The Society shall hold its Annual Meeting in New York City on the Monday preceding the first Tuesday in December, and such other meetings shall be held at such times and places as the Council may appoint. Twenty-five Members and Associates shall constitute a quorum for the transaction of business.

C 34. Special meetings of the Society may be called at any time at the discretion of the Council or shall be called by the President upon the written request of twenty-five members entitled to vote.

C 35. Any appropriation recommended by the Society at a meeting shall not take effect until it has been approved by the Council.

C 36. Every question which shall come before a meeting of the Society or of the Council or a Committee shall be decided by a majority of the votes cast, unless otherwise provided in this Constitution or the By-Laws, or the Laws of the State of New York. The Council may order the submission of any question to the membership for discussion by letter ballot. Any meeting of the Society at which a quorum is present may order the submission of any question to the membership for discussion by letter ballot.

STANDING COMMITTEES.

C 37. The standing committees of the Society shall be:

Finance Committee.

Publication Committee.

Membership Committee.

The members of these Committees shall be appointed by the President from members of the Council who are not officers of the Society.

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TRANSACTIONS.

C 38. The Society shall not be responsible for statements or opinions advanced in papers or in discussions at its meetings. Matters relating to politics, religion or purely to trade shall not be discussed at a meeting of the Society, nor be included in the Transactions.

C 39. The Society shall not approve any engineering or commercial enterprise, nor allow its imprint or name to be used in any commercial work or business. No member shall describe himself in connection with the Society in any advertisement other than as a Member, Associate Member or Junior Member.

AMENDMENTS.

C 40. At annual meetings of the Society any Member or Associate may propose in writing for discussion an amendment to this Constitution. Such proposed amendment shall not be voted on at that meeting, but shall be open for discussion and such modification as may be accepted by the proposer. The proposed amendment shall be mailed by the Secretary to each Member and Associate at the time the notice of the Annual Meeting issues, and shall be voted upon at said meeting.

C 41. Such By-Laws shall be enacted as will conform with this Constitution and the Laws of the State of New York and as are required to conduct the business of the Society.

BY-LAWS.

CANDIDATES FOR MEMBERSHIP.

B 1. A candidate for admission to the Society as a Member or as an Associate must make application on a form approved by the Council, upon which he shall write a statement giving a complete account of his qualifications and engineering experience, and an agreement that he will, if elected, conform to the Constitution, By-Laws and Rules of the Society. He must refer to at least four Members or Associates to whom he is personally known.

B 2. Applications for membership from Refrigerating Engineers who are not residents in the United States or Canada and who may be so situated as not to be personally known to four Members or Associates of the Society, as required in the foregoing paragraph, may be recommended for ballot by four members of the Council, after sufficient evidence has been secured to show that in their opinion the applicant is worthy of admission to the grade which he seeks.

B 3. A candidate for admission to the Society as a Junior must make application in the same manner as provided for Members or Associates, except that he must refer to not less than three Members or Associates to whom he is personally known.

B 4. The references for each candidate for admission to the Society shall be requested to make a confidential communication to the Membership Committee, setting forth in detail such information, personally known to the

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referee, as shall enable the Council to arrive at a proper estimate of the eligibility of the candidate for admission to the Society.

ELECTION OF MEMBERS.

B 5. The Secretary shall mail to each member entitled to vote, at least thirty days in advance of any meeting, a ballot stating the names and the respective grades of the candidates for membership in the Society which have been approved by the Council, and the time of the closure of voting. The voter shall prepare his ballot by crossing out the names of candidates rejected by him, and shall enclose said ballot in a sealed blank ballot envelope, which he shall then enclose in a second sealed outer envelope, on which he shall, for identification, write his name in ink. The ballot thus prepared and enclosed shall be mailed or delivered unopened to the Tellers of Election. The Secretary shall certify to the competency and the signature of all voters. On the closure of voting, the Tellers of Election shall first open and destroy the outer envelopes, and shall then canvass the ballots, and certify the result to the meeting of the Society.

B 6. The Tellers of Election shall not receive any ballot after the stated time of the closure of voting. A ballot without the endorsement of the voter written in ink on the outer envelope is defective, and shall be rejected by the Tellers of Election.

B 7. The names of those persons elected to membership, with their respective grades, shall be embodied in a written report, signed by the Tellers, and presented to the next meeting of the Society. The President shall then declare them duly elected to membership in the Society. The Tellers may, through the Secretary, in advance of any meeting, advise each candidate of the result of the canvass of the votes in his case. The names of applicants who are not elected shall neither be announced nor recorded in the Transactions.

B 8. The endorsers of an applicant who has not been elected may, with his consent, present to the Council a written request for a re-submission of his name to ballot. The Council may, in its discretion, by a three-fourths vote of the members present, order the name of the applicant placed on the next ballot for members.

B 9. Each person elected to membership must subscribe to the Constitution, By-Laws and Rules of the Society, and pay the initiation fee before he can receive a certificate of membership in the Society.

ELECTION OF OFFICERS.

B 10. The Secretary shall mail to each member entitled to vote, at least thirty days before the Annual Meeting, the names of the candidates for office proposed for election by the Nominating Committees.

B 11. The names of the candidates proposed by the Nominating Committee or Committees, and the respective offices for which they are candidates, shall be printed in separate lists on the same ballot sheet, each list of candidates to be printed under the names of the members of the particular committee which proposed it.

B 12. The name of any candidate on the ballot may be erased, and the

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name of any person qualified to hold office written in its stead. The ballot must be voted and canvassed in the same manner as for the election of members.

B 13. In case of a tie in the vote for any officer, the President, or, in his absence, the Presiding Officer, shall cast the deciding vote.

B 14. A ballot which contains more names on it than there are officers to be elected is thereby defective, and shall be rejected by the Tellers.

FEES AND DUES.

B 15. The initiation fee and annual dues of the first year shall be due and payable on notice of election to membership. Thereafter the annual dues shall be due and payable on the first day of December in each year.

B 16. A Member in arrears for one year shall not be entitled to vote until such arrears have been paid. Should the right to vote be questioned, the books of the Society shall be conclusive evidence.

B 17. The Secretary shall present to the Council the name of any Member, Associate or Junior in arrears for more than one year. A person dropped from the rolls for non-payment of dues may, at the discretion of the Council, be restored to the privileges of membership upon payment of all arrears.

FINANCIAL ADMINISTRATION.

B 18. The Council at its first meeting in each fiscal year shall consider the recommendations of the Finance Committee concerning the expenditures necessary for the work of the Society during that year. The apportioning of the work of the Society among the various standing and other Committees shall be on a basis approved by the Council and in harmony with the Constitution and By-Laws. The appropriations approved by the Council, or so much thereof as may be required for the work of the Society, shall be expended by the various Committees of the Society, and all bills against the Society for such expenditures shall be certified by the Committee making the expenditure, and shall then be sent to the Finance Committee for audit. Money shall not be paid out by any officer or employee of the Society except upon bills duly audited by the Committee, or by resolution of the Council.

FINANCE COMMITTEE.

B 19. The Finance Committee shall consist of three members of the Council appointed for a term of one year. The Committee shall, under the direction of the Council, have supervision of the financial affairs of the Society, including the books of account.

PROGRAMME COMMITTEE.

B 20. The President shall appoint a committee from the members of the Council who shall procure professional papers, to pass upon their suitability for presentation, and to suggest topical subjects for discussion at the meetings. The Committee may refer any paper presented to the Society to a person or persons, especially qualified by theoretical knowledge or practical experience, for their suggestions or opinions as to the suitability of the paper

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for presentation. Papers from non-members shall not be accepted except by unanimous vote of the Committee. No paper intended for publication in the Transactions of the Society shall be read at the meetings of this Society, unless a copy of it shall have been mailed to each member in printed or typewritten form at least two weeks before the date of the meeting at which it is expected to be read. It shall be the duty of the Programme Committee to cause such copies to be so mailed. This rule shall not apply to lectures or addresses offered by persons invited to deliver them by the unanimous vote of the Programme Committee. The Committee shall arrange the programme of each meeting of the Society, and shall have general charge of the entertainments to be provided for the members and guests at each meeting. It shall prohibit the distribution or exhibition at the headquarters or at the meeting places of the Society of all advertising circulars, pamphlets or samples of commercial apparatus or machinery. At the end of each fiscal year the Committee shall deliver to the Secretary for presentation to the Council a detailed report of its work.

PUBLICATION COMMITTEE.

B 21. The Publication Committee shall consist of three members of the Council appointed for a term of one year. The Committee shall review all papers and discussions which have been presented at the meetings, and shall decide what papers or discussions, or parts of the same, shall be printed. No papers shall be published, or authorized to be published, either publicly or privately, purporting to be a part of the transaction of the Society without the authority of the Publication Committee. At the end of each fiscal year the Committee shall deliver to the Secretary for presentation to the Council a detailed report of its work.

MEMBERSHIP COMMITTEE.

B 22. The Membership Committee shall consist of three members of the Council appointed for a term of one year. It shall be the duty of this Committee:

To receive and scrutinize all applications for membership to the Society.

To seek further information as to the qualifications of any applicant whose evidence of eligibility is not clear to the Committee.

To report to each session of the Council the names of all applicants under consideration, together with the action of the Committee on each.

The Committee shall at once destroy all correspondence in relation to each applicant when his name has been placed on the ballot by order of the Council, or upon the withdrawal of the application.

NOMINATING COMMITTEES.

B 23. A Nominating Committee of five Members or Associates shall be appointed by the President within three months after he assumes office. It shall be the duty of this Committee to send to the Secretary on or before October first the names of consenting nominees for the elective offices next falling vacant under the Constitution. Upon the request of any Member or

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Associate, the Secretary shall furnish to the applicant the name of such nominees.

B 24. Twenty or more members entitled to vote may constitute themselves a Special Nominating Committee with the same powers as the Annual Nominating Committee. A Special Nominating Committee, if organized, shall, on or before October twentieth, present to the Secretary the names of the candidates nominated by it for the elective offices next falling vacant under the Constitution, together with the written consent of each.

TELLERS.

B 25. The Presiding Officer shall, at the first session of the Annual Meeting, appoint three Tellers of Election of Officers, whose duties shall be to canvass the votes cast, and report the result to the meeting. Their term of office shall terminate when their report of the canvass is presented to the meeting.

B 26. The President, within one month after assuming office, shall appoint three Tellers of Election of Members to serve for one year, whose duties shall be to canvass the votes cast for members during the year, and to certify the same to the President. They shall notify candidates through the Secretary of the result of such election.

B 27. The President shall appoint three Tellers to canvass any letter ballots which shall be ordered by the Council or by the Society.

SECRETARY.

B 28. The Secretary of the Society shall be the Secretary to the Council.

The Secretary shall have charge of the Books of Account of the Society, under the supervision of the Finance Committee.

He shall make and collect all bills against members or others.

All bills against the Society shall be delivered to the Secretary. He shall immediately enter them in the books of Account, and shall immediately deposit such funds as he receives to the credit of the Society in a bank to be designated by the Council.

TREASURER.

B 29. The Treasurer shall make payments only on the audit of the Finance Committee, or upon the direction of the Council, by resolution of that body. He shall furnish a bond for the faithful performance of his duties to such amount as the Council may require, such bond to be procured from an incorporated guarantee company at the expense of the Society.

TITLES, EMBLEMS, CERTIFICATES.

B 30. Each Member, Associate and Junior shall, subject to such rules as the Council may establish, be entitled on request to a certificate of membership, signed by the President and Secretary of the Society. Every such certificate shall remain the property of the Society, and shall be returned to it on demand of the Council.

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B 31. Each proxy authorizing a person to vote for an absent member shall be signed by such absent member, with an attesting witness, and be submitted to the Secretary for verification of the member's right to vote at the meeting at which the right is to be exercised.

B 32. The emblem of each grade of membership approved by the Council shall be worn by those only who belong to that grade. The official stationery shall be used only by officers and committees of the Society for official business.

B 33. The abbreviations of the titles of the various grades of membership approved by the Society are as follows:

For Members—Mem. Am. Soc. R. E.
For Associates—Assoc. Am. Soc. R. E.
For Juniors—Jun. Am. Soc. R. E.

ORDER OF BUSINESS.

B 34. Roll call.
Reading of minutes of previous meeting.
Report of Tellers of Election of Membership.
Report of the Council.
Unfinished business.
New business.
Report of Tellers of Election of Officers.
Reading of papers and discussions.

PARLIAMENTARY RULES.

B 35. In all questions arising at any meeting, involving parliamentary rules not provided for in these By-Laws, "Cushing's Manual" shall be the governing authority.

AMENDMENTS.

B 36. These By-Laws may be amended in the same manner as amendments are made to the Constitution.

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PROCEEDINGS

OF THE

EIGHTH ANNUAL MEETING

NEW YORK, N. Y., December 2 and 3, 1912.

The American Society of Refrigerating Engineers held its eighth annual meeting in the Engineering Societies' Building, No. 29 West Thirty-ninth street, New York, N. Y., on Monday and Tuesday, December 2 and 3, 1912. Five sessions were held, Monday morning, afternoon and evening, and Tuesday morning and afternoon, all being called to order and presided over by President Thomas Shipley, York, Pa.

First Session, Monday Morning, December 2

The first session of the meeting was called to order about 11 o'clock A. M., and, as more than a quorum for the transaction of business was present, President Shipley announced that the calling of the roll would be dispensed with.

The minutes of the seventh annual meeting were then read and approved.

The next order of business was the report of the Tellers of Election of Membership. It follows:

NEW YORK, N. Y., November 23, 1912.

MR. THOMAS SHIPLEY, President,
The American Society of Refrigerating Engineers,
154 Nassau Street, New York, N. Y.

DEAR SIR:—Your Tellers of Election of Membership met to-day and canvassed the ballots for new members. We find one hundred and thirty ballots were cast, of which two were void for the lack of signatures on the outer envelopes.

We find that the following applicants have been duly elected to membership in the grades indicated:

MEMBER

George Braungart, Jr...Atlanta, Ga.
Arthur E. Edwards...Renton, Wash.
E. M. Holcombe.....Carbondale, Pa.
Oliver C. Irwin.....DeKalb, Ill.
Frederick F. Judd.....Boston, Mass.
George M. Kleucker..St. Louis, Mo.
Robert M. McCandlish, Kansas City, Mo.
Malcolm S MacDonald, London, England

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MEMBER—*Continued*

Horace J. Macintire..Pittsburgh, Pa.
Robert F. Massa...New York, N. Y.
Walter R. Nifong, Oklahoma City, Okla.
George H. Palmer..New York, N. Y.
Karl W. Schantz.....Buffalo, N. Y.
John M. Westerlin.....Chicago, Ill.
Richard Wildridge.Sydney, Australia
Levi F. Yeakley....Philadelphia, Pa.

ASSOCIATE MEMBER

T. A. Adams.....New York, N. Y.
George E. Chamberlin.St. Louis, Mo.
Hermann Dannenbaum, Philadelphia, Pa.
Caleb W. Dawley..McAlester, Okla.
Harry M. Edwards.New York, N. Y.
Paul E. Flotron....New York, N. Y.
Arthur G. Freeland.New York, N. Y.
Horace H. Judson..New York, N. Y.
Dale R. Mason.....Pittsburgh, Pa.
John A. Rasbury.....Atlanta, Ga.
Oscar Stevenson.....Chester, Pa.

JUNIOR MEMBER

Ernest W. Dibley..Sydney, Australia
William J. Donkel.Jersey City, N. J.
John E. Forgy.....Wilmington, Del.
Charles H. Herter..New York, N. Y.
Leonard W. Horr....La Grange, Ill.
Samuel Patersen...Philadelphia, Pa.
Jaroslav Spinka.....St. Louis, Mo.
Hilbert C. Wallber..Milwaukee, Wis.
Frederick A. Weisenbach, Philadelphia, Pa.

FOR CHANGE OF GRADE OF MEMBERSHIP FROM JUNIOR MEMBER TO MEMBER

Van R. H. Greene..New York, N. Y.
Robert H. Karl.....St. Louis, Mo.

Respectfully submitted,

(Signed) FRANK J. FLOCKE, Chairman,
VAN R. H. GREENE,
JOHN R. LIVEZEY,
Tellers of Election of Membership.

The president then declared the successful applicants for membership duly elected to their respective grades and entitled to the rights and privileges of membership, provided they had complied with the provisions of the constitution and by-laws relating to new members.

The report of the Council was next in order. It follows:

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REPORT OF THE COUNCIL OF THE AMERICAN SOCIETY OF REFRIGERATING ENGINEERS FOR THE YEAR ENDING NOVEMBER 30, 1912

The Finance Committee's report contains all the receipts and disbursements of the Society during the year. It follows:

REPORT OF FINANCE COMMITTEE

NEW YORK, N. Y., November 30, 1912.

MR. THOMAS SHIPLEY, President,
The American Society of Refrigerating Engineers,
154 Nassau Street, New York, N. Y.

DEAR SIR:—Your Finance Committee begs to report as follows for the fiscal year ending November 30, 1912:

Balance on hand December 2, 1911		$217.85
RECEIPTS		
Initiation fees	$185.00	
Dues	2,495.39	
Emblems, sales	24.75	
Dinner tickets	325.50	
Transactions, sales	101.00	
Total		3,131.64
Grand total		$3,349.49
DISBURSEMENTS		
Printing	$983.47	
Caterers	300.55	
Rents	297.60	
Salaries	900.00	
Stenographic transcript, seventh annual meeting	53.40	
Physical Constants Committee	35.52	
Dues, American Association of Refrigeration	100.00	
Premium on Treasurer's bond	10.00	
Emblems	2.25	
Membership certificates	10.00	
Petty cash	255.72	
Total		2,948.51
Balance on hand		$400.98

Respectfully submitted,

(Signed) LOUIS BLOCK, *Chairman.*

The Council held two executive sessions during the year—March 22 and October 16—and it respectfully presents herewith a report of the business transacted at these meetings, along with other matters that should be of interest to the membership.

At the first meeting on March 22, W. H. Ross was reappointed Secretary of the Society, and $900 was appropriated to cover his salary and the services of an office stenographer for the year ending Novemger 30, 1912.

The Publication Committee was authorized to print 500 copies of the 1912 Year Book, as well as 500 copies each of Volumes V, VI and VII—1909, 1910 and 1911—of the Transactions. The Year Book was issued promptly after the meeting of the Council on March 22, and Volume V of the Transactions was mailed to the membership on September 5. Volume VI of the

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Transactions has been printed and is now being bound and will be mailed within thirty days. Considerable work has been done on Volume VII, and this should be issued to the membership early next year. All of the papers of Volume VIII, 1912, of the Transactions are in type, and this volume should reach the membership around the middle of next year, providing the finances of the Society will permit of this expenditure at that time.

The membership will probably be interested to know that while some money has been appropriated each year to cover the services of the Secretary and the services of an office stenographer, the amount appropriated, after the expenditures of his office have been paid, leaves him practically nothing for his work. The labor incidental to the activities of the Secretary's office has increased each year, and it has now reached a point in the affairs of our Society when it is necessary to appropriate additional money for an assistant to the Secretary or employ one of our members to give the affairs of the Society practically his entire time.

The income of the Society in the form of initiation fees and dues, as now assessed, is not enough to meet the expense of the Society if an assistant must be employed or the entire services of some member secured. It will, therefore, be necessary to either increase the dues to, say, $15 per year for Members and Associate Members and $10 per year for Junior Members, or the membership must contribute to a fund to make up the deficit each year until the membership of the Society is large enough to meet its operating expenses on the present dues.

By increasing the dues to $15 the work of the Society can be done promptly, the Transactions issued in the earliest possible time, and other valuable features established that will increase the value of a membership in the Society.

The Council respectfully submits this matter to the membership for their earnest consideration, and we hope some definite step towards meeting the legitimate expenses of the Society is made at this meeting.

While 36 new members will be elected this year, making a total membership of 286, it will be necessary for us to increase the total number of our members to at least 450 before the Society will be on a paying basis on our present assessment for dues. Still, if all our members would be prompt in the payment of their dues, we might be able to place the Society on a paying basis with a total membership of only 400.

Your President announced the following committee appointments on March 22:

MEMBERSHIP COMMITTEE

Henry Torrance, Jr., Chairman, New York, N. Y.
Carl Behn, New York, N. Y.
Louis Doelling, New York, N. Y.

FINANCE COMMITTEE

Louis Block, Chairman, New York, N. Y.
Charles L. Case, East Boston, Mass.
Charles Dickerman, Philadelphia, Pa.

PUBLICATION COMMITTEE

Theodore O. Vilter, Chairman, Milwaukee, Wis.
Victor H. Becker, Chicago, Ill.
Albert Ruemmeli, St. Louis, Mo.

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PROGRAMME COMMITTEE

Carl Behn, Chairman, New York, N. Y.
Henry Torrance, Jr., New York, N. Y.
Theodore O. Vilter, Milwaukee, Wis.
Louis Doelling, New York, N. Y.
Gardiner T. Voorhees, New York, N. Y.

NOMINATING COMMITTEE

Edward N. Friedmann, Chairman, New York, N. Y.
R. H. Tait, St. Louis, Mo.
Louis Block, New York, N. Y.
Edgar Penney, Newburgh, N. Y.
D. S. Jacobus, New York, N. Y.

TELLERS OF ELECTION OF MEMBERSHIP

Frank J. Flocke, Chairman, New York, N. Y.
V. R. H. Greene, New York, N. Y.
John R. Livezey, Philadelphia, Pa.

An appropriation of $50 was made to cover the expenditures of the Physical Constants Committee in visiting Dr. S. W. Stratton, Chief of the Bureau of Standards, at Washington, D. C., relative to the Bureau of Standards co-operating with the Physical Constants Committee in its work. The Physical Constants Committee has drawn on the Treasurer for $35.52 of this appropriation.

On request of the Publication Committee for instructions as to printing the paper read by Dr. J. E. Siebel on "The Thermodynamics of Saturated Vapors and Related Problems of Energy" at our Chicago meeting in 1909, in Volume V of the Transactions, the committee was instructed to print this paper in this volume, giving Dr. Charles E. Lucke the right to reply to Dr. Siebel's contentions, and Dr. Siebel the right to make an author's closure, as per precedent established in past volumes. However, later, Dr. Siebel withdrew his paper.

At the meeting of the Council on March 22, Edward N. Friedmann was appointed a Director to fill the unexpired term of President Shipley.

The resolutions passed by the Engineers' Club of St. Louis, Mo., on December 6, 1911, relative to requesting President Taft to urge Congress to establish a Patent Court, or Patent Commission, were endorsed by the Council on March 22. The resolutions are as follows:

RESOLUTIONS OF ENGINEERS' CLUB OF ST. LOUIS

WHEREAS, There exists a widespread dissatisfaction with the system of legal procedure under which patent cases are adjudicated, which dissatisfaction frequently finds expression in a demand for the establishment by Congress of a special Patent Court or Patent Commission, in the same way that such tribunals as the Inter-State Commerce Commission, the Court of Commerce and the Court of Claims has been established; and,

WHEREAS, A patent may be adjudged valid in one circuit and invalid in another circuit of concurrent jurisdiction, resulting in the anomalous condition that in the same circuit one party may be prohibited by one court from making, using or selling the patented device, while another party (not the owner of the patent) may make, use or sell a device exactly similar to that of the first party because another court has ruled the patent invalid as to him; and,

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WHEREAS, There is no limit to the time during which an applicant for a patent may continue to urge his views upon the Patent Office in an effort to have included claims which the Patent Office thinks should not be allowed, thereby giving an opportunity to the applicant to incorporate in his specification and claims ideas obtained from progress made in the art subsequent to the filing of the original application, and thereby also unduly deferring the beginning and ending of the life of the patent; and,

WHEREAS, Reissues with broadened claims may be granted after intervening rights have accrued to others, and without public notice that such reissue is contemplated, thus making it necessary for these others to go to the expense of litigation to protect themselves against the consequences of acts which, at the time such acts were performed, did not infringe the original patent; and,

WHEREAS, A patent after having been duly issued may be placed in interference with a pending application, at the same time preventing the public from making, using or selling the device of the patent during the course of the interference proceedings; and in the event that the rights of invention are adjudged to lie in the application and to be vested in the owner of the application, a firm or individual, by controlling both the patent and the application, may secure virtual monopoly rights for a longer period than the seventeen (17) years given by act of Congress as a reward for inventive genius;

Therefore be it Resolved, That the Engineers' Club of St. Louis respectfully calls the attention of the President of the United States to the conditions herein outlined, and, further, that it respectfully requests that he incorporate in a message to Congress a recommendation that remedial legislation be enacted.

Resolved, Further, that copies of these resolutions be sent to the members of the Cabinet and of Congress, and to the executive officers of other engineering and technical organizations, with a request for action endorsing them.

The invitations of the Eighth International Congress of Applied Chemistry and the Sixth Congress of the International Association for Testing Materials, both held in New York the past year, to have representatives of this Society attend these congresses, resulted in a motion being passed authorizing your President to appoint three members to represent the Society at each of these congresses. Your President appointed H. Dannenbaum, Philadelphia, Pa.; William H. Bower, Philadelphia, Pa., and Morgan B. Smith, Syracuse, N. Y., to represent the Society at the Eighth International Congress of Applied Chemistry and Dr. D. S. Jacobus, New York, N. Y.; Frederick L. Pryor, Hoboken, N. J., and Dr. Charles E. Lucke, New York, N. Y., to represent the Society at the Sixth Congress of the International Association for Testing Materials.

At the meeting of the Council on October 16 the resignations of the following members were accepted with regret:

W. Fellows Morgan, New York, N. Y.
William Nottberg, Kansas City, Mo.
Walter C. Reid, New York, N. Y.
M. W. Thompson, Greensboro, N. C.
Morgan B. Smith, Detroit, Mich.
C. H. Parsons, Springfield, Mass.
G. H. Delareuelle, Oakland, Cal.

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The Membership Committee presented the following approved applications for membership, and they have received the favorable action of the Council in the grades indicated:

MEMBER

George Braungart, Jr...Atlanta, Ga.
Arthur E. Edwards..Renton, Wash.
E. M. Holcombe.....Carbondale, Pa
Oliver C. Irwin.....DeKalb, Ill.
Frederick F. Judd.....Boston, Mass.
George M. Kleucker..St. Louis, Mo.
Robert M. McCandlish, Kansas City, Mo.
Malcolm S. MacDonald.Chicago, Ill.
Horace J. Macintire..Pittsburgh, Pa.
Robert F. Massa...New York, N. Y.
Walter R. Nifong, Oklahoma City, Okla.
George H. Palmer.New York, N. Y.
Karl H. Schantz.....Buffalo, N. Y.
John M. Westerlin.....Chicago, Ill.
Richard Wildridge.Sydney, Australia
Levi F. Yeakley....Philadelphia, Pa.

ASSOCIATE MEMBER

T. A. Adams.....New York, N. Y.
George E. Chamberlin.St. Louis, Mo.
Hermann Dannenbaum, Philadelphia, Pa.
Caleb W. Dawley..McAlester, Okla.
Harry M. Edwards.New York, N. Y.
Paul E. Flotron....New York, N. Y.
Arthur G. Freeland.New York, N. Y.
Horace H. Judson..New York, N. Y.
Dale R. Mason.....Pittsburgh, Pa.
John A. Rasbury.....Atlanta, Ga.
Oscar Stevenson.....Chester, Pa.

JUNIOR MEMBER

Ernest W. Dibley..Sydney, Australia
William J. Donkel.Jersey City, N. J.
John E. Forgy.....Wilmington, Del.
Charles H. Herter..New York, N. Y.
Leonard W. Horr....La Grange, Ill.
Samuel Petersen...Philadelphia, Pa.
Jaroslav Spinka.....St. Louis, Mo.
Hilbert C. Wallber..Milwaukee, Wis.
Frederick A. Weisenbach, Philadelphia, Pa.

FOR CHANGE OF GRADE OF MEMBERSHIP FROM JUNIOR MEMBER TO MEMBER

Robert H. Karl.....St. Louis, Mo.
Van R. H. Greene..New York, N. Y.

Eight applications for membership have been received since the last ballots for new members were issued.

The invitation of Harry A. Wheeler, President of the Chamber of Commerce of the United States of America, that the Society become a member of that body, was declined, for the reason that this Society is not an industrial organization, and the Council felt that the members of the Society would be represented in the Chamber of Commerce of the United States of America through their trade and local organizations.

Your President has appointed the following members as Tellers of Election of Officers:

S. P. Stevenson, Chester, Pa.
G. H. Fisher, Leavenworth, Kan.
N. H. Hiller, Carbondale, Pa.

We regret to announce the death of the following members since our last report, and we hope suitable resolutions will be offered on their life work:

Frank H. Hier, Cincinnati, Ohio.
Victor H. Becker, Chicago, Ill.
Clifford E. Huntley, New York, N. Y.
Carlos Maschwitz, Buenos Ayres, Argentine Republic.
J. M. Smart, New York, N. Y.

On invitation of President J. B. White, of the Fourth National Conservation Congress, that was held in Indianapolis, Ind., on October 1, 2, 3

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and 4, your President appointed the following members to represent the Society at this congress:

R. H. Tait, St. Louis, Mo.
Henry Vogt, Louisville, Ky.
J. S. Louis, Cincinnati, Ohio.
G. A. Robertson, Louisville, Ky.
A. P. Criswell, Chicago, Ill.

It has been suggested that the Society hold a meeting in Chicago next year, when the Third International Congress of Refrigeration meets there. The officials of the Congress have also suggested that a day during the Congress be set apart to be known as "Refrigerating Engineers' Day," over which the members of this Society may officiate. The Council respectfully requests the suggestions of the membership on this subject.

Respectfully submitted,

(Signed) THOMAS SHIPLEY, *President.*

The next order of business was unfinished business, and President Shipley first called for a report of the Physical Constants Committee. In the absence of its chairman, Charles E. Lucke, the Secretary reported as follows:

The members of the Physical Constants Committee had an interview with Dr. S. W. Stratton, Chief of the Bureau of Standards, in Washington, D. C., during the past spring, relative to checking the physical constants employed in refrigeration. Dr. Stratton stated that he would be very glad to do the work, but he had neither the men nor the complete equipment nor an appropriation to do it. He suggested, however, that if we could induce Congress to make an appropriation to cover this proposed work he would be very glad to take the matter up promptly. The committee had laid out a plan of procedure in this matter, and were preparing to begin an active campaign among members of both houses of Congress when the American Association of Refrigeration held its annual meeting in Washington. At the meeting of this association this matter also received attention, and with the co-operation of nearly all of the organizations and associations interested in refrigeration, an ititial appropriation of $15,000 was secured from Congress to begin this work. The Bureau of Standards is now preparing to do this work, and Dr. Stratton hopes to have some of the work completed in time to present the result to the Third International Congress of Refrigeration in Chicago next fall. Additional appropriations, of course, are necessary, probably $20,000 each year for the next two years.

President Shipley also remarked as follows on this subject:

This is a matter of great interest to us. Those who have attempted to analyze the data we have at the present time have no doubt found that there are many discrepancies, hence we are unable to make proper comparisons or to prove the work we have done. For this reason the necessity of the exact determination of our physical constants is plain to us all. You know the money outlay in checking these constants is very great, and that we cannot expect any private enterprise to work it out. Consequently, we must look to the Government to do it for us and so we must get the money from

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Congress. The Bureau of Standards cannot do it of its own volition, and it must have means to do the work. The only way this can be done is through our friends the politicians, and since we elect the politicians it is up to us to get busy and persuade them to give us our quota of the money used by the Government for investigations. The Government is spending large sums of money on investigations in other lines of industry and we should get our share of it when we consider the taxes we pay. When this subject was first introduced at our Chicago meeting, it was suggested that the Illinois Experiment Station might also take up this work, and we would be pleased to hear from the committee of Illinois members having this matter in charge.

F. W. Pilsbry stated that V. H. Becker had this matter in charge, but as he had since died he did not know what had become of it.

W. E. Mosher, of the Illinois Experiment Station, was present and stated that they had proposed to take up the work, but that as no funds were available for doing it in an experimental way, it was taken up as a theoretical study, and that this had been his work for a year and a half. However, he stated that when they learned that the Bureau ond Standards had taken up the work in an experimental way, the Illinois Experiment Station abandoned the idea of taking up the work experimentally.

A report was now called for from the Third International Congrees of Refrigeration Fund Committee. In the absence of its chairman, Louis Block, the Secretary stated that he understood it was the purpose of this committee to begin the collection of this fund in 1913.

The Committee on Suggesting a Standard Tonnage Basis of Refrigeration and a Standard Method of Testing Refrigerating Machinery, which is acting jointly with a similar committee of The American Society of Mechanical Engineers, was now asked for its report. In the absence of other members of the committee, President Shipley reported as follows:

I wish to call your attention to the problems which this committee has before it and the stone walls which it is up against. A standard table by which to rate all different kinds of refrigerating machines is quite some problem. That is one of the stumbling blocks we are up against, and, if you stop to think, you will find that it is quite a proposition. A machine of any type can be given an endless variety of capacities. Now suppose you try to get up a rule that will cover all types of machines. This cannot be done in a minute. The Bureau of Standards may be able to help in these problems, and its help will certainly count. At our works we have not as yet been able to get up a rule that will cover all the different classes of machinery that we build. I believe this committee is really waiting for the determinations of the Bureau of Standards before making at least a preliminary report. This is a very important matter to all of us, for we all realize the benefits we must

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derive if we can discover some basis upon which all machines can be figured. Until this is done there is bound to be a lot of misunderstanding as to capacity. Maybe some one here has suggestions to make on this subject.

Peter Neff remarked of the variations in the latent heat of ice of the several authorities, ranging from 142 to 144 B. t. u. He further stated that the Bureau of Standards wrote him that the Government is using 143.5 at the present time, and he thought that if we used the Government figures until this matter was definitely determined, matters would harmonize along this line.

President Shipley thought 144 B. t. u. was the most convenient figure to use, as this gave 200 B. t. u. per minute per ton.

The amendments to sections S 20 and C 26 of the Constitution, introduced by W. H. Ross at the seventh annual meeting, were now taken up for final discussion and action.

Where section C 20 now reads—

"The affairs of the Society shall be managed by a Board of Directors chosen from among its Members and Associates, which shall be styled 'The Council.' The Council shall consist of the President of the Society, who shall be the presiding officer, the two Vice-Presidents, Treasurer and nine Members or Associates. Seven members of the Council shall constitute a quorum for the transaction of business. The Secretary may take part in the deliberations of the Council, but shall not have a vote therein."

The proposer would have it read—

The affairs of the Society shall be managed by a Board of Directors chosen from among its Members and Associates, which shall be styled "The Council." The Council shall consist of the President of the Society, who shall be the presiding officer, the two Vice-Presidents, Treasurer and *fifteen* Members and Associates. Seven Members of the Council shall constitute a quorum for the transaction of business. The Secretary may take part in the deliberations of the Council, but shall not have a vote therein.

This increase in the number of directors also necessitates an amendment to section C 26 of the Constitution. So where the fifth paragraph of section C 26 reads—

"Nine Members or Associates shall be elected to the Council at the first Annual Meeting, three to hold office for one year, three to hold office for two years, and three to hold office for three years, and at each subsequent Annual Meeting three Members or Associates shall be elected, each to serve three years."

The proposer would have it read —

Fifteen Members or Associates shall be members of the Council, five being elected each year, and each to hold office for three years, with the exceptions contained in this paragraph. On the year of acceptance of this amendment (1912), and in order to increase the number of Directors from

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nine, as heretofore, to fifteen, as provided in this paragraph and in amended Section C 20, nine Members or Associates shall be elected to the Council, five to hold office for three years, two to hold office for two years, and two to hold office for one year, thereafter five Members or Associates shall be elected each year. This amendment shall not affect the term of office of Directors elected prior to its adoption.

Both of these amendments received unanimous approval.

President Shipley then appointed J. F. Nickerson, Chicago, Ill.; F. W. Pilsbry, Chicago, Ill., and Walter L. Hill, Boston, Mass., as a Resolutions Committee to draft a memorial on the lives of the members who had died during the past year, with the special request that they also include the names of Fred W. Wolf and H. Rassbach.

The matter of the deficit of the Society and the suggested increase in dues, mentioned in the report of the Council, was now brought to the attention of the meeting.

The following amendment to the Constitution was offered by the Council for discussion and modification, and final action at the ninth annual meeting.

Where section C 17 now reads—

C 17. The initiation fee for membership shall be as follows:
For Members and Associates, five dollars.
For Juniors, five dollars.
A Junior on promotion to any other grade of membership shall pay an additional fee of five dollars.
The annual dues for membership shall be as follows:
For Members and Associates, ten dollars.
For Juniors, five dollars for the first six years of their membership, and thereafter the same as for a Member or Associate.

The Council would have it read—

C 17. The initiation fee for membership shall be as follows:
For Members and Associates, five dollars.
For Juniors, five dollars.
A Junior on promotion to any other grade of membership shall pay an additional fee of five dollars.
The annual dues for membership shall be as follows:
For Members and Associates, *fifteen* dollars.
For Juniors, *ten* dollars for the first six years of their membership, and thereafter the same as for a Member or Associate.

As to the deficit, the Secretary reported it as about $1,500, and, while the matter was referred to the Council with power to act, several members promised a contribution of $100 each.

It was suggested that it would be desirable to hold a meeting of

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the Society in Chicago during the time of the Third International Congress of Refrigeration, and an expression was made to this effect to guide the Council in this matter.

The report of the Tellers of Election of Officers was now received through its chairman, S. P. Stevenson, Chester, Pa. It follows:

NEW YORK, N. Y., December 2, 1912.

MR. THOMAS SHIPLEY, President,
The American Society of Refrigerating Engineers,
154 Nassau Street, New York, N. Y.

DEAR SIR:—We have to report that we have canvassed the ballots for officers for the ensuing year, and beg to report that 112 ballots were cast, 4 of which were void. The vote was as follows:

FOR PRESIDENT

Peter Neff, Canton, Ohio	105
Henry Torrance, Jr., New York, N. Y	1

FOR VICE-PRESIDENT

Theodore Kolischer, Philadelphia, Pa	105
Karl Wegemann, New York, N. Y	1

FOR TREASURER

Frank A. Horne, New York, N. Y	107

FOR DIRECTORS

(Terms expire at annual meeting of 1915)

Carl Behn, New York, N. Y	107
Ezra Frick, Waynesboro, Pa	107
Thomas Shipley, York, Pa	106
P. DeC. Ball, St. Louis, Mo	107
John Levey, Chicago, Ill	107
Carl Vollmann, Montreal, Canada	1

(Terms expire at annual meeting of 1914)

L. C. Nordmeyer, St. Louis, Mo	107
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(Terms expire at annual meeting of 1913)

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We therefore find that the following have been elected to the offices indicated:

President—Peter Neff.
Vice-President—Theodore Kolischer.
Treasurer—Frank A. Horne.
Directors—

(Terms expire at annual meeting of 1915)

Carl Behn.
Ezra Frick.
Thomas Shipley.
P. DeC. Ball.
John Levey.

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(Terms expire at annual meeting of 1914)

L. C. Nordmeyer. J. H. Stone.

(Terms expire at annual meeting of 1913)

Henry Vogt. C. H. Young.

Respectfully submitted,

(Signed) S. P. Stevenson, *Chairman* } *Tellers of Election of Officers.*
N. H. Hiller,
George H. Fisher,

President Shipley declared the new officers formally elected and requested ex-Presidents Louis Block and Edward N. Friedmann to escort President-elect Neff to the platform.

In accepting the presidency Mr. Neff said:

Mr. President and Members of the Society, I appreciate most highly the honor conferred upon me, and assure you that I will use my best endeavors to promote the welfare of the Society—and remember that success can only come from co-operation, and I feel sure that I will secure that at your hands. I thank you.

The session now adjourned for luncheon in the Engineers' Club, as arranged by the Program Committee.

Second Session, Monday Afternoon, December 2.

The second session was called to order shortly before 2 o'clock P. M. and the following communication and invitation were introduced:

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

No. 29 West Thirty-ninth Street
New York, N. Y., December 2, 1912.

The American Society of Refrigerating Engineers,
Mr. W. H. Ross, Secretary.

My Dear Mr. Ross:—The American Society of Mechanical Engineers extends its greetings to The American Society of Refrigerating Engineers in convention, and cordially invites its members and friends to make themselves at home at all times in our rooms on the eleventh floor.

There will be a reception Tuesday evening, December 3, to the retiring President, Dr. Humphreys and Mrs. Humphreys, and to the President-elect, Dr. W. F. M. Goss and Mrs. Goss, to which all the members of your Society and friends are invited. On Thursday evening, December 5, there will be the award of the John Fritz Medal to Mr. Robert W. Hunt, of Chicago, following which there will be a reception in honor of Mr. Hunt, given by the three Societies of Mining, Electrical and Mechanical Engineers to the members of the other engineering societies, to which the members of your Society and friends are again most cordially invited.

Yours very truly,

(Signed) Calvin W. Rice, *Secretary.*

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The pleasure of your company
is requested by the
American Institute of Mining Engineers,
American Society of Mechanical Engineers,
American Institute of Electrical Engineers,
at a Joint Reception to

ROBERT WOOLSTON HUNT,

Engineering Societies Building,
Twenty-nine West Thirty-ninth Street, New York,
on the evening of Thursday, December the Fifth,
Nineteen Hundred and Twelve,
at eight-thirty o'clock.

The John Fritz Medal for 1912 will be awarded by the Board of Award, which is made up of representatives of the three above-named societies and the American Society of Civil Engineers. This Medal is awarded to Mr. Hunt for "His contributions to the early development of the Bessemer Process."

THE JOHN FRITZ MEDAL BOARD OF AWARD

American Society of Civil Engineers	American Institute of Mining Engineers	American Society of Mechanical Engineers.
Charles Macdonald.	E. Gybbon Spilsbury.	W. F. M. Goss.
Onward Bates.	Robert V. Norris.	Henry R. Towne.
Charles Warren Hunt.	Charles Kirchhoff.	John A. Brashear.
M. T. Endicott.	James F. Kemp.	F. R. Hutton.

American Institute of Electrical Engineers.

Louis A. Ferguson.
Lewis B. Stillwell.
Dugald C. Jackson.
Guano Dunn.

RECEPTION COMMITTEE

John A. Brashear.	F. R. Hutton.	Robert V. Norris.
Guano Dunn.	Dugald C. Jackson.	E. Gybbon Spilsbury.
Louis A. Ferguson.	James F. Kemp.	Lewis B. Stillwell.
W. F. M. Goss.	Charles Kirchhoff.	Henry R. Towne.
Alex. C. Humphreys.	Ralph D. Mershon.	

It was moved, seconded and carried that the communications be received and votes of thanks were extended to both The American Society of Mechanical Engineers and its secretary, Calvin W. Rice.

The address of President Shipley on "The State of the Art" was the next order of business. His remarks were closely followed and generously applauded.

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The reading and discussion of papers was now taken up. Those presented at this session were "Liqgas—A Possible New State of Matter," by Gardner T. Voorhees, New York, N. Y., and "The Gas Engine on Refrigerating Work," by E. W. Gallenkamp, Jr., St. Louis, Mo.

The topics, "The Use of Ice in Refrigerator Cars in Winter to Prevent Freezing of Perishable Products in Transit" and "Loss of Refrigeration at Doorways of Refrigerated Rooms," were also discussed at this session.

The session now adjourned.

Third Session, Monday Evening, December 2

The third session of the meeting was called to order at 8 o'clock P. M.

The papers presented at this session were "Avoidable Accidents in Refrigerating Plants," by Louis Block, New York, N. Y., and "Ammonia Compressor Safety Devices," by Peter Neff, Canton, Ohio.

The Cold Storage Legislation Committee, through its chairman, Henry Torrance, Jr., reported that very little cold storage legislation had been introduced in the State legislatures during the past year, and that his committee had practically done no work. The committee was continued.

The session then adjourned.

Fourth Session, Tuesday Morning, December 3

The fourth session of the meeting was called to order at 9:30 A. M.

The following telegram from Theodore O. Vilter, Milwaukee, Wis., was brought before the meeting:

THE WESTERN UNION TELEGRAPH COMPANY

MILWAUKEE, WIS., December 2, 1912.

Mr. W. H. Ross, 154 Nassau Street, New York, N. Y.

Will thank you to present to the meeting of The American Society of Refrigerating Engineers the question of standardization of ammonia fittings on the same basis as steam fittings. Requested by American Association of Refrigeration, which appointed a committee at their last convention. Have such information from members, but would like an impression from engineers of your Society, also interested manufacturers.

THEODORE O. VILTER, *Chairman*,
Standardization of Ammonia Fittings Committee,
American Association of Refrigeration.

Action on it was deferred until the last session of the meeting.

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A telegram of greeting and regrets was also read from ex-President Edgar Penney.

The papers read at this session were "The Manufacture of Distilled Water Can Ice," by N. H. Hiller, Carbondale, Pa., and "Atmospheric Dehumidifying," by J. I. Lyle, New York, N. Y.

The session then adjourned for luncheon in the Engineers' Club.

Fifth Session, Tuesday Afternoon, December 3

The fifth and final session of the meeting was called to order promptly at 1:30 P. M.

The papers read at this session were "Corrosion in Refrigerating Systems," by Morgan B. Smith, Detroit, Mich.; "Physical Properties of Anhydrous Ammonia," by Lionel S. Marks and F. W. Loomis, of Harvard University, and "Properties of Saturated and Superheated Ammonia," by William Earl Mosher, of the University of Illinois.

A hearty vote of thanks was extended Mr. Smith, Mr. Marks, Mr. Loomis and Mr. Mosher for their very valuable papers.

Ex-President John E. Starr then offered the following resolution, which was accepted:

RESOLUTION ON TEMPORARY PHYSICAL CONSTANTS

WHEREAS, There appears in the different tabulations of the properties of ammonia and carbon dioxide wide variations, and that there also appears to be considerable difference in the opinions of physicists as to the reliability of such tabulations; and,

WHEREAS, Different tabulations are used by refrigerating engineers resulting in wide differences of calculation, both as to capacity and efficiency; and,

WHEREAS, The Bureau of Standards of the United States has undertaken to take up the entire work of the determination of the physical properties of carbon dioxide and ammonia, but that this work will take some years to complete; and,

WHEREAS, In the case of ammonia the widest difference in the tabulations probably gives theoretical results well within the error of commercial tests; therefore be it

Resolved, That a committee of this Society be appointed to select from the latest and best information obtainable tabulations of the properties of ammonia and carbon dioxide and the latent heat of ice, and to prepare tables of the same, which shall be used by the members of this Society, after the committee's report has been approved by the Society, as the official data of the properties of ammonia, carbon dioxide and ice, until such time as definite and authoritative tables are issued by the United States Bureau of Standards and accepted by our leading physicists. This committee to be instructed to report at the summer meeting of this Society.

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A motion prevailed that this committee consist of five members, including President Shipley, who left the appointing of the other members of the committee to the incoming president.

The next order of business was the discussion of the topic, "Things New in Refrigerating Practice." Under this heading Louis Block and President Shipley described their new types of ammonia condensers.

The appointing of a committee on standardization of ammonia fittings, as suggested in the telegram from Theodore O. Vilter, read at the fourth session of the meeting, was next considered, and a motion prevailed authorizing the appointment of such a committee to consist of manufacturers of ammonia fittings. President Shipley left this duty to the incoming president.

The Resolutions Committee now made its report through its chairman, J. F. Nickerson, Chicago, Ill. It was accepted and it follows:

Report of Resolutions Committee

The members of The American Society of Refrigerating Engineers, assembled in eighth annual meeting, recognize that of their number there are missing since the previous annual meeting, several whom the Angel of Death has summoned to the Great Beyond, and resting a moment from their deliberations, take this occasion to pay humble tribute to the memory of those who are gone.

The list of friends and fellow workers whom we shall see no more this side of the grave is as follows:

Victor H. Becker, died November 15, 1912—Refrigerating engineer and associate editor of "Ice and Refrigeration," Chicago, Ill.

Frank T. Hier, died February 2, 1912—Secretary-Treasurer and general manager of Cincinnati Ice Manufacturing & Cold Storage Co., Cincinnati, Ohio.

Clifford E. Huntley, died November 14, 1912—Engineer and architect, New York, N. Y.

Carlos Maschwitz, died 1911—President of the Maschwitz-Rey Co., Buenos Aires, Argentine Republic.

J. Montgomery Smart, died April 14, 1912—Refrigerating engineer and President of the American Cold Storage & Shipping Co., New York, N. Y.

The Society deplores the loss of these valued members, and extends to their relatives and associates all the sympathy of warm hearts and affectionate remembrance.

It is also fitting that this Society takes cognizance of the death of two distinguished refrigerating engineers, not members of the Society, who have passed away during the last year.

In the death of Fred. W. Wolff, of Chicago, Ill., engineer and president of the Fred. W. Wolf Co., one of the pioneers in the building of refrigerating machinery, who has spent a lifetime in this work, and who contributed so

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greatly towards improvement of the art and progress of refrigeration, this Society and the refrigerating industries have sustained an irreparable loss.

In the death of Hermann Rassbach, of Atlanta, Ga., refrigerating engineer, the Society and the industry in general have lost a most valued and esteemed member of the profession. Being one of the oldest engineers in point of service and an indefatigable worker, the art of refrigeration owes much to his efforts and talent. Therefore be it

Resolved, That this Society expresses its appreciation of the great loss the industry has sustained in the death of these two men, and that the Society extends its sincere sympathy to the relatives and associates of the deceased; and be it

Further resolved, That this memorial be spread upon the minutes of the Society and a copy of same be sent to the families of the departed.

(Signed) J. F. NICKERSON, *Chairman,*
F. W. PILSBRY,
WALTER L. HILL.
} *Resolutions Committee.*

A resolution also prevailed authorizing the appointment of a committee to suggest a standard basis for finding the fuel economy of steam-driven ice manufacturing plants. The appointment of this committee was left to the incoming president.

A hearty and unanimous vote of thanks was extended to President Shipley for the exceptionally able manner in which he has conducted the affairs of the Society during his term of office.

The meeting then adjourned.

W. H. ROSS, *Secretary.*

MEMBERS AND GUESTS ATTENDING EIGHTH ANNUAL MEETING

Allison, C. E., New York, N. Y.
Bates, Guy, Summit, N. J.
Berna, George, Ithaca, N. Y.
Binzel, Peter, Jr., New York, N. Y.
Block, Louis, New York, N. Y.
Borgstedt, H., New York, N. Y.
Bower, W. H., Philadelphia, Pa.
Bracken, John H., Chicago, Ill.
Brangs, Paul H., New York, N. Y.
Bridgette, R. E., Brooklyn, N. Y.
Bunnell, S. H., New York, N. Y.
Busch, W. A., New York, N. Y.
Byrne, Frederick J., New York, N. Y.
Carpenter, R. C., Ithaca, N. Y.
Cole, Harold W., New York, N. Y.
Crawford, Gilbert, Jr., Washington, D. C.
Cross, D. A., Brooklyn, N. Y.
Dannenbaum, H., Philadelphia, Pa.
Dahlquist, C., Brooklyn, N. Y.
Day, Abram, Bloomfield, N. J.
Dickerman, Charles, Philadelphia, Pa.
Dohrmann, William H., Brooklyn, N. Y.
Donkel, William J., Jersey City, N. J.
Duffy, F., New York, N. Y.
Edwards, H. M., New York, N. Y.
Ely, James, New York, N. Y.
Fairbanks, F. L., Boston, Mass.
Farish, J. F., New York, N. Y.
Fisher, G. H., Leavenworth, Kan.
Fitzsimmons, J. E., New York, N. Y.
Flotron, Paul E., New York, N. Y.
Forgy, J. E., Wilmington, Del.
Friday, A. H., New York, N. Y.
Friedmann, E. N., New York, N. Y.

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Girard, L. H., New York, N. Y.
Glatfelter, P. H., Spring Grove, Pa.
Glatfelter, W. L., York, Pa.
Goosmann, J. C., Chicago, Ill.
Gott, Joseph, Jr., New York, N. Y.
Green, H. D., New York, N. Y.
Greene, Van R. H., New York, N. Y.
Greenwald, J., New York, N. Y.
Hall, R. M., New York, N. Y.
Hargreaves, William, New York, N. Y.
Haring, W. J., Woodcliff, N. J.
Hartmann, E. C., Chicago, Ill.
Heckel, E. P., New York, N. Y.
Herter, Charles H., New York, N. Y.
Hill, J., New York, N. Y.
Hill, W. L., Boston, Mass.
Hiller, N. H., Carbondale, Pa.
Hoffmann, W. John, New York, N. Y.
Holcombe, E. M., Carbondale, Pa.
Horne, George A., New York, N. Y.
Hovey, Charles A., New York, N. Y.
Howe, Arthur E., Philadelphia, Pa.
Ives, Arthur S., New York, N. Y.
Irwin, B., Brooklyn, N. Y.
Irwin, Robert V., New York, N. Y.
Jenks, L. H., New York, N. Y.
Judd, F. F., Boston, Mass.
Judson, H. H., New York, N. Y.
Kehoe, Robert P., New York, N. Y.
Kellegrew, F. W., New York, N. Y.
Kessler, R., Brooklyn, N. Y.
Kolischer, Theodore, Philadelphia, Pa.
Laiman, Theodore W., Hartford, Conn.
Lake, E. F., Cleveland, Ohio.
Lane, George H., New York, N. Y.
Langdon, G. M., New York, N. Y.
Lau, F. H., Jr., New York, N. Y.
Lewis, E. W., Chicago, Ill.
Livezey, John R., Philadelphia, Pa.
Lyle, J. I., New York, N. Y.
McPartlin, S. E., Chicago, Ill.
Macdonald, D. H., New Bedford, Mass.
Magher, A. E., New York, N. Y.
Marks, Harry J., New York, N. Y.
Marks, Lionel S., Cambridge, Mass.
Marshall, A. T., Hartford, Conn.
Matthews, F. E., New York, N. Y.
Mason, D. R., Pittsburgh, Pa.
Massa, R. F., New York, N. Y.
Michaelis, G. V. S., New York, N. Y.
Miller, J. F., New York, N. Y.
Monks, W. D., New York, N. Y.
Mosher, William Earl, Urbana, Ill.
Murphy, E. J., New York, N. Y.
Narath, William G., New York, N. Y.
Neeson, C. R., New York, N. Y.
Neff, Peter, Canton, Ohio.
Neubecker, J., New York, N. Y.
Newham, H. S., New York, N. Y.
Nickerson, J. F., Chicago, Ill.
Nifong, W. R., Oklahoma City, Okla.
Nolde, Fred., New York, N. Y.
Orrok, A. H., New York, N. Y.
Petersen, Samuel, Philadelphia, Pa.
Phillips, E. A., Philadelphia, Pa.
Pilsbry, F. W., Chicago, Ill.
Plock, John L., New York, N. Y.
Pryor, F. C., Hoboken, N. J.
Ramsey, L. A., New York, N. Y.
Reilly, J. P., New York, N. Y.
Richardson, G. P., Newark, N. J.
Rice, Calvin W., New York, N. Y.
Richmond, H., New York, N. Y.
Rodgers, Charles W., New York, N. Y.
Roland, C. F., New York, N. Y.
Ross, A. C., New York, N. Y.
Ross, W. H., New York, N. Y.
Rowe, Samuel J., Coatesville, Pa.
Russell, F. S., Chicago, Ill.
Schantz, K. W., Buffalo, N. Y.
Schmidt, C. R., Baltimore, Md.
Seeman, W. E., Brooklyn, N. Y.
Shipley, R. T., York, Pa.
Shipley, S. J., New York, N. Y.
Shipley, Thomas, York, Pa.
Shipley, W. S., New York, N. Y.
Smith, Guy B., Brooklyn, N. Y.
Smith, Herbert E., Boston, Mass.
Smith, Morgan B., Chicago, Ill.
Smith, M. R., Brooklyn, N. Y.
Smyth, S. F., Brooklyn, N. Y.
Spangler, F. C., Brooklyn, N. Y.

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Sparks, John C., New York, N. Y.
Starr, John E., New York, N. Y.
Stern, Paul, Ponce, P. R.
Stevens, C. N., Brooklyn, N. Y.
Stevenson, S. P., Chester, Pa.
Stoddard, George H., Boston, Mass.
Stone, J. H., New York, N. Y.
Strickler, A. B., York, Pa.
Sutton, W. S., New York, N. Y.
Thomson, George H., New York, N. Y.
Torrance, Henry, Jr., New York, N. Y.
Ulrick, C. W., New York, N. Y.
Vesterdahl, Karl, New York, N. Y.
Vetter, H., Jr., New York, N. Y.
Vogt, Clarence W., Louisville, Ky.
Vogt, Henry, Louisville, Ky.
Wagner, George A., New York, N. Y.
Warner, Irving, Wilmington, Del.
Watt, J. J., New York, N. Y.
Weager, T. A., New York, N. Y.
Webber, W. J., Boston, Mass.
Wegemann, Karl, New York, N. Y.
Weigand, C., New York, N. Y.
Weisenbach, F. A., Philadelphia, Pa.
Wenz, August, Brooklyn, N. Y.
Williams, E. T., New York, N. Y.
Wills, W. H., New York, N. Y.
Wilson, Thomas, New York, N. Y.
Wolf, Fred. W., Chicago, Ill.
Wood, Harold B., Hudson, N. Y.
Yeakley, L. F., Philadelphia, Pa.
Young, Conrad H., New York, N. Y.

BANQUET.

The annual banquet of the Society was held in the elaborately appointed restaurant of Louis Martin, on Broadway, near Forty-second street. About 150 members and guests enjoyed the occasion, the largest in point of attendance.

It was evident that every one came to have a good time, and it was truly a love feast, mingled with music, songs and witty and funny stories. John E. Starr, New York, N. Y., acted as toastmaster, and he was at his best.

Addresses were made by President-elect Neff, Louis Block, New York, N. Y.; President Shipley, J. F. Farish, New York, N. Y.; Charles Dickerman, Philadelphia, Pa.; G. V. S. Michaelis, New York, N. Y.; E. N. Friedmann, New York, N. Y.; J. F. Nickerson, Chicago, Ill.; Theodore Kolischer, Philadelphia, Pa.; John Hill, New York, N. Y., and L. H. Jenks, New York, N. Y. "Connie" Young also told the funniest of his funny stories.

Members and Guests Attending Banquet

Allison, C. E., New York, N. Y.
Binzel, Peter, Jr., New York, N. Y.
Block, Louis, New York, N .Y.
Borgstedt, H., New York, N. Y.
Bower, W. H., Philadelphia, Pa.
Bridgette, R. E., Brooklyn, N. Y.
Busch, W. A., New York, N. Y.
Crawford, Gilbert, Jr., Washington, D. C.
Dannenbaum, Hermann, Philadelphia, Pa.
Dickerman, Charles, Philadelphia, Pa.
Dohrmann, William H., Brooklyn, N. Y.
Duffy, F., New York, N. Y.
Edwards, H. M., New York, N. Y.
Ely, James, New York, N. Y.
Farish, J. F., New York, N. Y.

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Fisher, G. H., Leavenworth, Kan.
Fitzsimmons, J. E., New York, N. Y.
Friedmann, E. N. New York, N. Y.
Glatfelter, P. H., Spring Grove, Pa.
Glatfelter, W. L., York, Pa.
Green, H. D., New York, N. Y.
Greene, Van R. H., New York, N. Y.
Greenwald, J., New York, N. Y.
Hall, Robert M., New York, N. Y.
Hargreaves, William, New York, N. Y.
Herter, Charles H., New York, N. Y.
Hill, John, New York, N. Y.
Hill, Walter L., Boston, Mass.
Hiller, N. H., Carbondale, Pa.
Hoffmann, W. John, New York, N. Y.
Holcombe, E. M., Carbondale, Pa.
Hovey, Charles A., New York, N. Y.
Howe, Arthur E., Philadelphia, Pa.
Irwin, Robert V., New York, N. Y.
Ives, Arthur S., New York, N. Y.
Jenks, L. H., New York, N. Y.
Judd, F. F., Boston, Mass.
Kehoe, Robert P., New York, N. Y.
Kellegrew, F. W., New York, N. Y.
Kolischer, T., Philadelphia, Pa.
Laiman, Theodore W., Hartford, Conn.
Lane, George H., New York, N. Y.
Langdon, G. M., New York, N. Y.
Lewis, E. W., Chicago, Ill.
Livezey, John R., Philadelphia, Pa.
Lau, F. H., Jr., New York, N. Y.
Lyle, J. I., New York, N. Y.
Magher, A. E., New York, N. Y.
Mason, D. R., Pittsburgh, Pa.
Massa, R. F., New York, N. Y.
Matthews, F. E., New York, N. Y.
Michaelis, G. V. S., New York, N. Y.
Miller, J. F., New York, N. Y.
Monks, W. D., New York, N. Y.
Murphy, E. J., New York, N. Y.
Narath, William G., New York, N. Y.
Nickerson, J. F., Chicago, Ill.
Neeson, C. R., New York, N. Y.
Neff, Peter, Canton, Ohio.
Newham, H. S., New York, N. Y.
Nifong, W. R., Oklahoma City, Okla.
Nolde, Fred., New York, N. Y.
Orrok, A. H., New York, N. Y.
Petersen, Samuel, Philadelphia, Pa.
Phillips, E. A., Philadelphia, Pa.
Pilsbry, F. W., Chicago, Ill.
Plock, John L., New York, N. Y.
Ramsey, L. A., New York, N. Y.
Reilly, J. P., New York, N. Y.
Richardson, G. P., Newark, N. J.
Rodgers, C. W., New York, N. Y.
Ross, A. C., New York, N. Y.
Ross, W. H., New York, N. Y.
Russell, F. S., Chicago, Ill.
Seemann, W. E., Brooklyn, N. Y.
Shipley, R. T., York, Pa.
Shipley, S. J., New York, N. Y.
Shipley, Thomas, York, Pa.
Shipley, W. S., New York, N. Y.
Smith, Guy B., Brooklyn, N. Y.
Smyth, S. F., Brooklyn, N. Y.
Spangler, F. C., Brooklyn, N. Y.
Stevenson, S. P., Chester, Pa.
Strickler, A. B., York, Pa.
Starr, John E., New York, N. Y.
Stone, J. H., New York, N. Y.
Sutton, W. S., New York, N. Y.
Thomson, George H., New York, N. Y.
Torrance, Henry, Jr., New York, N. Y.
Vetter, H., Jr., New York, N. Y.
Vogt, Clarence W., Louisville, Ky.
Vogt, Henry, Louisville, Ky.
Watt, J. J., New York, N. Y.
Webber, W. J., Boston, Mass.
Wegemann, Karl, New York, N. Y.
Weisenbach, F. A., Philadelphia, Pa.
Weigand, C., New York, N. Y.
Wenz, August, Brooklyn, N. Y.
Wills, W. H., New York, N. Y.
Wolf, Fred. W., Chicago, Ill.
Yeakley, L. F., Philadelphia, Pa.
Young, C. H., New York, N. Y.

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No. 99

PRESIDENTIAL ADDRESS—THE STATE OF THE ART.

THOMAS SHIPLEY, YORK, PA.

In the address made by the president on occasions like this a society naturally expects the theme to be the object for which that particular society was organized to promote. This, to my mind, is a very wise usage, and one which I will endeavor to follow in the brief address which I am privileged to make you.

In discussing the state of the art of our profession I will confine myself, as near as possible, to developments which have taken place during interim of my administration as your president. You will understand, however, that my point of view must necessarily be closer to the arts than to the sciences of our calling, and by reason of that point of view I am a better authority on the practical side of questions relating to our profession and business than I am on the scientific side.

My position in the battle we are fighting is in the manufacturers' corps of the army, and that corps is always on the firing line, where action and initiative are necessary to keep one from being swept off his feet and buried among the failures.

Since I am the first man from our corps whom you have honored with the presidency of this Society, I believe it will not be out of order to remind you that the work done by the manufacturers' corps is not a dress parade affair. It is a case of load and fire with us all the time, and we must shoot to kill or we will be killed, and those of you who belong to the war colleges and the ammunition department must not forget that your work is very different from ours.

Your well-laid plans to conquer the enemy's country necessarily take a great amount of thought and an endless amount of research to bring them into the shape you present them, but to put your plans into practice is quite another matter. The conditions and quantities which you have assumed as a basis for your formulæ are exact, whereas in the practical working out of your theories and conclusions the conditions and quantities to be met are beyond the control

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of those to whom the task is given. Therein comes the difficulty. If the manufacturers' corps could foretell the exact position and condition of the enemy, then it would require little brain work and much less brawn to prove the truth or falsity of your dreams.

The enemy of to-day is not armed with bow-guns and clubs. He has rifles equal to those we have been furnished with; hence we must not only shoot but shoot straight. We must strike a weak spot in the opponent's defense or we can make no impression upon his works. To succeed we must have not only the very best of arms and ammunition but we must use them effectively or we are lost.

Let me also remind you that while you strut around in gold lace we are in our service uniforms which are durable but not pretty. And while you are enthusing the raw recruits and drilling the awkward squads, remember you are putting it up to us to bring practical results from the theories you advocate. If you have used the wrong symbol in your formulæ, or made an error in your deductions, you correct them with a "Please pardon me," while with us a mistake means disaster and oblivion. We must make good or be failures. Our ear must ever be on the ground to note the direction from which the enemy comes, and we must be prepared to meet him at all points, and if we are a little harsh in our language and our manner is not to your liking, don't think it is because we do not appreciate the work your divisions are doing, but believe it is because of our strenuous life, and that with us the difference between Success and Failure is so small that we must take as few chances as possible, lest we are relegated to the rear as cripples or dead ones. We must ever be on the alert to recognize, secure and use new methods to gain our ends, or our armor is pierced and we are placed among the Back Numbers.

And still, to take up every new idea or scheme presented to us would be impossible from every standpoint. Our commanders are expected to be able to discriminate between the methods which are necessary to success and those which would lead to failure, or they must step aside for men who can.

You will understand that I am not apologizing for the men in our corps. I am only explaining why some of the theories, good and bad, which have been called to our attention are not put to practical use, thereby bringing fame and riches to their discoverers and advocates.

Many of you may be certain that the methods of attack suggested by you would have put the enemy to rout, but my belief is,

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were you in the field, where the guns get mired and the horses break their traces, you would soon learn why the batteries did not open fire at the precise second called for in the book of tactics, and you would find why it was necessary to leave the beaten road and take our men across the country to avoid being flanked by our adversaries. At the same time, you would be sure to discover that while theoretical knowledge is very necessary to success in the field, the emergencies arising there require a combination of "horse sense" and mathematics, with the accent on the horse.

Having cleared my mind of a few cobwebs and, incidentally, giving you some insight as to my point of view, you are possibly in a better position to put a true value upon my further remarks.

I cannot give you a general résumé of the arts and sciences connected with the new developments in refrigerating engineering, for my mind has been too much occupied by matters which demanded my attention in my position in the profession to allow me to stray far afield; hence I am forced to confine myself to those items of interest which caught my attention. There is no doubt whatever that many important things have escaped me, and for that reason I ask your indulgence if I do not call attention to matters which some of you have been investigating, and of which I know nothing, or on which I do not feel myself competent to give an official opinion.

Coal economy, to my mind, is the order of the day. Efforts are being made to design and build plants which will produce a ton of ice or its equivalent for the lowest possible fuel cost. This is particularly so in the ice-making field, where purchasers seem willing to take up with any new scheme to reduce the fuel cost, regardless as to whether or not the scheme has been properly tried out.

This has caused the loss of considerable money on both sides and has retarded the development of some good ideas.

The effort to reduce fuel cost has brought about many attempts to perfect the "raw water ice plant," as well as to make ice from distilled water produced by evaporator systems. These systems have made it possible to use gas engines, oil engines and electricity for power to drive such plants. And it has also made it possible to use low-pressure absorption systems.

Once the right combination to be used in treating the water to be frozen has been settled, no material trouble is experienced with the above systems; but until this is determined, trouble is a constant companion with any of them.

Ice made from raw water obtainable in some localities is as fine

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as can be desired, while in other localities raw water plants require an endless amount of water purifying apparatus and circulation devices, and even then the ice is not up to the A-1 standard. This is caused by the water containing gases and other impurities which cannot be eliminated by ordinary processes. Plants of identical design can be operated with little or no trouble in one locality, while in another locality they require very careful handling to produce marketable ice.

The same can be said of plants where the water to be frozen is obtained wholly or partly from evaporator systems. The troubles on these plants come usually from the gases contained in the water, and which have not been eliminated during the process of evaporation and condensation, the result of which is usually discoloration in the ice, or the trouble caused by incrustation forming upon the tubes in the evaporators, which condition soon reduces the efficiency of the apparatus below the requirements of the plant. Both of these troubles require special treatment, which adds to the cost of the ice, thereby reducing the saving contemplated.

Just how far it is profitable to go in the line of fuel economy is one of the greatest questions before the ice plant designer, and again and again the thought occurs to him, Does it really pay to put in the complicated and expensive machinery needed to produce these extreme coal economies, with the additional labor needed, together with the fact that a much better class of operators is required? The frequent stoppages in the operation of the plant, caused by the disarrangement or needed adjustment of more delicate apparatus, must also be considered in the item of expense of operation. And again the thought occurs, Does it pay in the long run? And also what the net saving will be, when the life of the apparatus is considered?

Would it not be wiser to pay more attention to the boiler plant?

And would it not pay to put in the most economical compressor?

Should not more attention be paid to the driving of auxiliaries?

These and many other kindred questions come up to plague the designer and those who own or operate ice plants.

Such questions, however, are determined very largely by the salesman, rather than by the engineer, or they may be determined by some engineer who has a hobby, who, by getting the ear of the purchaser, sets a pace for his competitors, either far in advance of the state of the art or off on a tangent from sound principles. In this way the purchaser, as well as the manufacturer, wakes up to find they must do considerable experimental and missionary work,

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principally for the benefit of everybody else in the business, for these trial trips cannot be hid; hence, after the victims, both vendor and vendee, have thrashed the matter out, the spectators proceed to take advantage of the lesson they have had an opportunity to observe, while the victims pay the bill—the one by losing money on his contract, and the other losing money by loss of business or the possession of a patched up plant, or both.

It must not be thought that these trial trips are confined to any particular individual or company. If this was a fact, that individual or company would soon go out of business. Every manufacturer in the business gets his opportunity to bite into a lemon. Indeed, one of the manager's greatest worries is the fear that he has allowed a "freak" to slip into his allotment of troubles.

Troubles of this kind are being rapidly reduced in number and size, owing to the efforts of this Society to make public information concerning the possibilities of refrigerating and ice-making machinery, thereby educating both the engineer and the purchaser so that both may profit by the experiences of others, instead of going it alone, as once was the practice.

Another very large factor which is working to the good of our profession is the vast number of technical men being turned out yearly by our colleges. These men are met at every turn of the road, and every one of them is from Missouri. He requests to be shown. This causes Mr. Salesman to "Stop, Look and Listen" and to go on the hunt for information and data to satisfy this requirement, for the salesman of to-day must be able to answer all questions from an engineering standpoint, and he, first of all, must have the education needed to follow up the questions involved. Then he must have the practical knowledge to be able to advise intelligently, or when he bumps up against a technical man, or the well-informed man, he finds he cannot make the impression he wishes, and, therefore, success is not his.

The sizes of the units called for to-day are stretching in each direction, large as well as small; 300, 400, 500 or 600 ton machines, having two single-acting or two double-acting compressors, are to be seen upon the erecting floors of our manufacturers almost at any time, while small machines, down to one ton or less, are standing around like soldiers on parade. The wonder is, what becomes of all these little fellows. The fact is, these small machines are being used for every conceivable purpose, their principal use, however, being where temperatures are required below that obtainable by the direct

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use of ice. So much machinery is used nowadays in every business enterprise that whenever refrigeration is needed in suitable quantity, the adding of an ice-making or refrigerating plant is one of the requirements to make the installation complete.

Possibly the greatest step in advance which has been made this year in refrigerating machinery is the bringing out of the ammonia condenser, where the ammonia gas is condensed by bringing it into direct contact with its liquid. With this type of condenser it is possible to do the same work with five square feet of surface as can be done with thirty square feet of surface in the ordinary type of atmospheric condenser—that is, with 80-degree water, a section containing 480 feet of two-inch pipe, of the ordinary type condenser, will do about ten tons' work, whereas, in the new type of condenser, having the same total feet of pipe (480 feet of 2-inch), divided into two sections, sixty tons of work can be done.

This means not only a great saving in first cost, but a much greater saving in space and structure required to take care of the apparatus, and, in addition to this, there is the saving in the cost of cleaning and upkeep, all of which is no small item.

Many other detail improvements have been made to apparatus used in connection with ice-making and refrigerating machinery, and a general movement is going on toward the standardization of ammonia fittings. When this has been accomplished a long step in advance will have been made.

Less and less of the "freaks" are being built in every direction, and it is to be hoped that the day is not far distant when the true efficiency of each type of compressor, and each type of absorption plant, will be determined and recognized, the same as is the case with machinery used in power plant installations, and the proper sphere for the use of the different refrigerants placed upon the market established. Then the "calamity howler" and the "man with the revolutionary plant" will not be so apt to disturb the peace of the community, and we will have more time to devote to legitimate business methods.

All who are active in either the scientific or practical work of our profession realize the great need which exists for scientific research in matters relating to problems to be met in the design, manufacture and operation of ice-making and refrigerating machinery, and since these data are needed for the good of the general public, it is only reasonable for us to look to the National Government to make what-

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ever experiments and investigations are needed to settle the questions involved.

There has been much work done by individuals, and also by our colleges, but the work yet to be done is so extensive and requires such exact apparatus and the expenditure of so much time in its determination that it would be out of the question to expect it to be done by private enterprise.

As you know, this Society is making efforts to induce the National Government to take up this matter, and our efforts have met with some success, and it is to be hoped that before another year rolls around the Bureau of Standards at Washington will have taken up this work and will have made a substantial start toward furnishing us data of this kind.

The approaching Third International Congress of Refrigeration, which is to be held at Chicago next year, is sure to furnish us with much valuable information, and each and every one of us should do his full duty in his endeavor to make the meeting not only a success, but also to show our foreign brothers what we have done and are doing to advance the arts and sciences relating to refrigerating engineering.

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No. 100

LIQGAS

A POSSIBLE NEW STATE OF MATTER, CO_2, THE CRITICAL POINT, ETC.

By Gardner T. Voorhees, New York, N. Y.
(Member of the Society)

In my investigations of the properties of Co_2 previous to my tests with it while in London during the past three years, I found it impossible to solve problems in refrigeration as we can with NH_3. A careful study of Amagat's and Mollier's work on CO_2 did not help me to solve such problems, but led me to attempt, by the use of their data, to discover a new way to do so.

The old claim that the latent heat of CO_2 was zero at the critical point seemed the best point to investigate.

As it had been well proven by others that CO_2 did actual refrigeration when the CO_2 to the expansion valve was above the critical point, I investigated the reason for this at great length and finally came to the conclusion that while CO_2 did not exist as a visible liquid at temperatures above its critical temperature, it nevertheless had latent heat at and above this temperature. With this assumption, and from the data of Amagat and Mollier, I then established by research and calculation values for the heat of CO_2 liquid or its equivalent at all temperatures likely to be used in refrigerating practice.

In all refrigerating problems the refrigerator pressure is lower than the critical pressure, and so I was able to solve all problems in a similar manner to that used in solving NH_3 problems.

The data I established in this way afterwards proved to be practically exact from actual tests made by me with CO_2 refrigerating machines. My investigations were for the use of my multiple effect compressor and multiple effect receiver for CO_2 machines in which I obtained over 100 per cent. more capacity and 50 per cent. better economy than with ordinary CO_2 machines of same swept volume at same speed.

In my apparatus I provided heavy glass windows, so I could observe the character and action of the CO_2 at any temperature and pressure while it was in the refrigerating machine circuit.

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From my observations I found that CO_2 was a clear, colorless liquid, like water, below the critical point, and that its vapor was clear and colorless, like air.

Just before the critical point the CO_2 was like a thin fog in appearance; near the critical point, the CO_2 was like a dense fog, so that six inches of it entirely cut off the light from a 32 candle-power lamp from shining through it; and at times, perhaps by the presence of some oil vapor from the compressor, the CO_2 near the critical point was of a dark, brick-red, or blood-red color. Just above the critical point the CO_2 again had the appearance of a thin fog, and further above the critical point the CO_2 looked like a clear, colorless, syruppy gas that was not liquid, resembling hot air with distinct lines of movement therein as may be seen in air over a heated surface on a calm day. I also saw the CO_2 change from the liquid to the critical state, when the visible liquid surface disappeared.

I further noticed the CO_2 change from the liquid to the solid state at a pressure considerably higher than that of the atmosphere, and in so doing the liquid seemed to pop and greatly increase its bulk, much like the action of popcorn.

From my calculations, before these experiments were made, I believed that in order to be workable in the refrigerating circuit, above the critical temperature, the CO_2 must have had other than its well-known properties. My actual practical work tended to confirm this belief.

It seems most probable that CO_2, from somewhat below to a good deal above the critical state, *has latent heat* different from that given in the tables, and that this latent heat is made up of two parts: First, the latent heat of the liquid; second, the specific heat of something else, and I believe this mixed matter is a new property which is probably common to all substances at or near to the critical point. This new property implies a new state of matter. Matter as at present defined can be solid, liquid, vapor, or gas. The supposed new state of matter is between that of liquid and gas, and somewhat akin to the vaporous state, and yet it has some of the properties of the liquid state and may be the solution of a liquid in a gas.

The supposed new state of matter seems to have latent heat, and this latent heat seems to be due to a change in the state of the matter from it to a liquid, and from it to a gas.

I propose the name of "Liqgas" for the new state of matter,

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so that a substance in this state may be said to be in the liqgaseous state.

I find that although CO_2 comes to the expansion valve as liqgas, with no visible sign of liquid or suspended liquid or vapor in it, but after passing the expansion valve to a pressure lower than the critical pressure, it is then part liquid and part vapor, just as if liquid had come to the expansion valve; and the probable action in passing the expansion valve is a compound one, where the CO_2 passes through the liqgaseous, vaporous and liquid states. The commonly accepted ideas of the critical point should be enlarged and modified.

I wish to be clear in that I do not declare that such a new state of matter does exist, but only point out that it may exist, and that at any rate investigations carried on to attempt to prove or disprove this will be most interesting and instructive.

DISCUSSION.

F. E. Matthews.—Mr. Voorhees seems to have tackled the problem from a thermo-dynamic as well as from an observation standpoint. I don't know that anyone has ever gone into it before from a thermo-dynamic standpoint to see whether or not there exists a property of matter similar to the latent heat of a liquid.

J. C. Goosmann.—Mr. Voorhees' paper goes into a subject that relates a so-called phenomenon—we have always treated it as a phenomenon because the reason for the action of carbonic acid in producing much better efficiencies than a gas expanding against a resistance was very clear to us and could not be denied, as actual test showed it. In a test which I made, the drop in capacity of the machine when working with temperatures above the supposed critical point of carbonic acid was not much more than 35 per cent. Now, if some change had not taken place, and we did not in some way derive benefit in addition to the latent heat of carbonic acid, it would not have been possible for the machine to lose only that much in capacity. The only plausible explanation that has come to me and to others who have observed it is—that the carbonic acid goes through the liquid pipe up to the expansion valve in the form of a compressed gas and not as a liquid. At the expansion valve occurs a decided drop of temperature, with the result that partial liquefaction of the carbonic acid takes place. That seems to me a more logical explanation and conclusion.

I don't know that we are justified in assuming that foreign gases, of which we have no knowledge, and which cannot be found

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except by analysis, may exist in carbonic acid and exert sufficient influence to maintain the capacity of the machine within 60 per cent. or 65 per cent. of normal.

President Shipley.—Then you don't believe that there is here a new discovery, but that it is only a condition?

J. C. Goosmann.—No, I don't think it is a new discovery, and the explanation I have made and the conclusion reached seem to me to be perfectly logical.

W. E. Mosher.—I feel, as Mr. Goosmann does, that it is simply a phenomenon which can be accounted for in a perfectly logical way, without calling for the existence of any new state of matter. It seems to me the explanation Mr. Goosmann has given, and which has occurred to other scientists, accounts for the facts which Mr. Voorhees has observed here. It does not seem to me that the existence of a new state of matter is necessary to explain the phenomenon.

President Shipley.—There is no use talking, our friend Voorhees has dug into these questions very deep. Sometimes we have rubbed it into him and laughed at him, and he got the best of us finally. Therefore, I believe we had better go slow; maybe he has dropped on to something again. It is a good thing to make him prove it, and that is what we always try to do. We never let up on Mr. Voorhees until he proves his allegation, but he has managed to work it over on us once in a while, and I don't discredit his suggestions. I think it would be just as well for us to take notice; possibly there may be something in his statements.

J. C. Goosmann.—I may add that the experiment Mr. Voorhees describes is one not entirely new. We all know that carbonic acid can exist in the same space as gas and as a liquid. To illustrate. we have little test glasses in which carbonic acid gas can be compressed in the gaseous state, and in these we can observe the carbonic acid in liquid as well as the gaseous state by merely changing the temperature.

F. E. Matthews.—I would like to ask Mr. Goosmann what becomes of the latent heat of volatilization where such a change takes place? Dou you supply sufficient heat to overcome the latent heat of volatilization?

J. C. Goosmann.—These little test glasses are necessarily small, owing to the high pressure required to produce liquefaction, and we usually apply heat sufficient to change the condition of the fluid from the liquid to the gaseous state. We usually hold it under a

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hydrant of running water to cool it down and get the gas back into the liquid state. In practical refrigeration we know that under certain temperature conditions we handle a liquid throughout the entire liquid pipe, and yet we can increase the capacity of the machine considerably by compressing the liquid to a great extent, and yet the volume of the liquid in the enclosed glass fills the entire space, but it seems we can crowd still more liquid carbonic acid into a given space, and that is something we can't do with water, as we all know.

President Shipley.—You believe, then, that liquid carbonic acid can be compressed?

J. C. Goosmann.—Yes. The manufacturers of liquid carbonic acid say the same thing, that they can crowd more liquid carbonic acid into the standard flasks, and, when they figure up the volume of the flasks, they find that it would be impossible to get so much liquid into them if it were not possible to compress the liquid.

President Shipley.—Does that answer your question, Mr. Matthews?

F. E. Matthews.—Yes, in a way, but I believe there must be something more in this quick transition from the liquid to the gaseous state. There is, as Mr. Voorhees describes, an almost instantaneous change and a rapid disappearing of the line of demarkation between the liquid and the gas. From the thermo-dynamic viewpoint that Mr. Voorhees takes, it does not look reasonable to me that when you are gradually heating up a glass tube full of this substance it could change suddenly from a liquid to a gas in the same volume, without taking up considerably more heat than you would have time to supply.

J. C. Goosmann.—I don't wish to tire you on the subject of carbonic acid; but as it is new to a considerable extent ot all of us, and we are always glad to learn, I shall reply further to Mr. Matthews. The latent heat of liquid carbonic acid is, as you all know, not as high per pound as the latent heat of ammonia. In fact, it is only about 130 B. t. u., and when we have a small quantity enclosed in a test tube it does not amount to a great deal in weight, and, therefore, the heat necessary to change it from the liquid to the gaseous condition also is not very great. Probably the heat of the hand alone is sufficient to bring about the change.

N. H. Hiller.—I would like to ask Mr. Goosman if the latent heat does not vary with the temperature, for, as the temperature

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rises and the latent heat falls, a point should be reached where there wouldn't be very much heat required to vaporize the liquid?

J. C. Goosmann.—Yes, there is a change in the latent heat with change of temperature, and the latent heat of the liquid I mentioned is based on a certain temperature of liquefaction, but the change is not very great so long as the gas is within the liquefiable condition.

President Shipley.—Are you satisfied with the information we have on the physical constants of carbonic acid, Mr. Goosmann, or do you believe further investigations are necessary to give you data to handle that substance to your satisfaction?

J. C. Goosmann.—I have come to this conclusion, that we are in a stage of practical development and progress in the final points of construction involving the efficiency of compressors, and that we actually obtain from carbonic acid much more work than our theory concedes. In fact, we obtain more work from the carbonic acid machine than we can figure out from any data furnished by scientists. Mollier's work, I understand, is the most accurate of all on the physical properties of carbonic acid.

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No. 101

THE GAS ENGINE ON REFRIGERATING WORK

By E. W. Gallenkamp, Jr., St. Louis, Mo.

(Member of the Society)

At the sixth annual meeting of this Society in 1910, R. H. Tait presented a paper entitled "A Gas Producer Operated Refrigerating Plant." It is the author's purpose in this paper to relate briefly the changes that were made to overcome the troubles mentioned in the previous paper and to submit some results which have been obtained.

MECHANICAL CHANGES

A comparison of the sketches will make clear the modifications made in the gas-cleaning apparatus. Fig. 1 shows the original and Fig. 2 and Fig. 3 the modified apparatus.

The gas no longer passes up through an uptake, *B*, Fig. 1, nor down through a tower scrubber, *C*, but directly into the hydraulic main,*D*, which is still in good condition, despite all predictions of its deterioration after six months. The tar extractor, *E*, was placed close to the hydraulic main and the by-pass around the blower was eliminated. Fig. 2 shows these changes. The blower is used only in starting the engine to insure gas at the intake valves. The hydraulic main was modified by cutting off the bottom one-third of the way up, partitioned in the middle, and the entire tank water-sealed, as shown in Fig. 3. The partition has a six-inch hole through which the gas must pass. A flat cast iron ring about six feet inside and eight feet outside diameter was placed upon the grate bars in the gas producer. Scrapers have been inserted in the connections between the producer and the hydraulic main.

OPERATION

The charging of the coal is left to the fireman, who has instructions to keep the fuel bed at a certain height. The fire is usually "poked down" and then the charge of coal dropped into the producer. The ashes are drawn once in three hours. Every two weeks the machine is shut down for three or four hours to clean the gas-cleaning apparatus and the ignitors on the engine.

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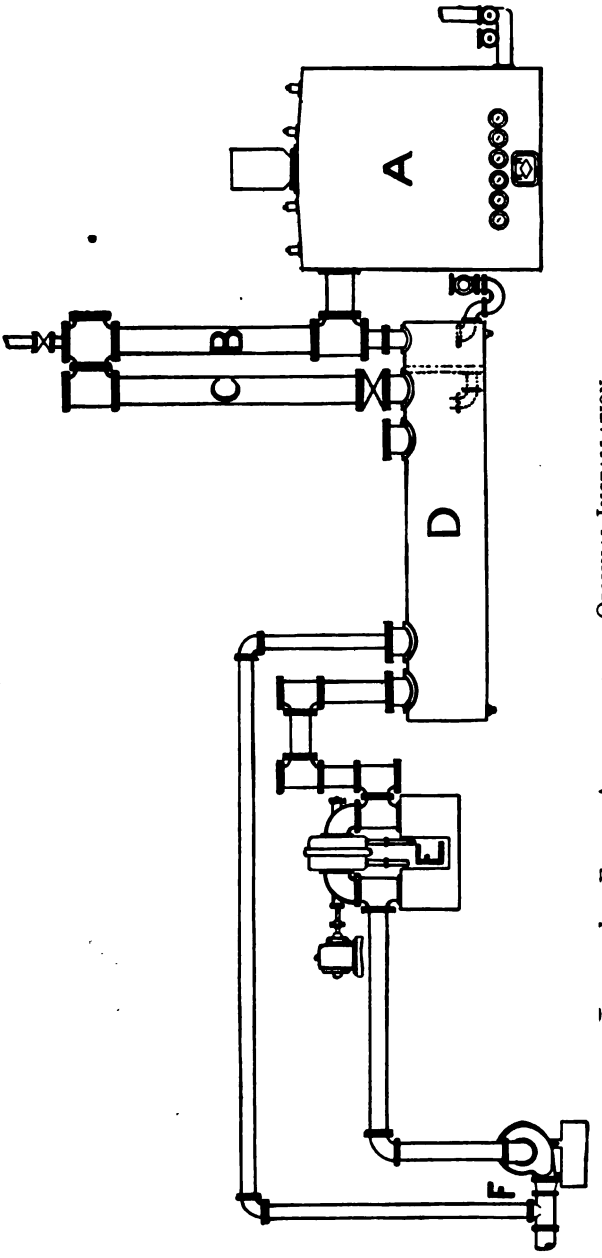

FIG. 1.—ARRANGEMENT OF ORIGINAL INSTALLATION.

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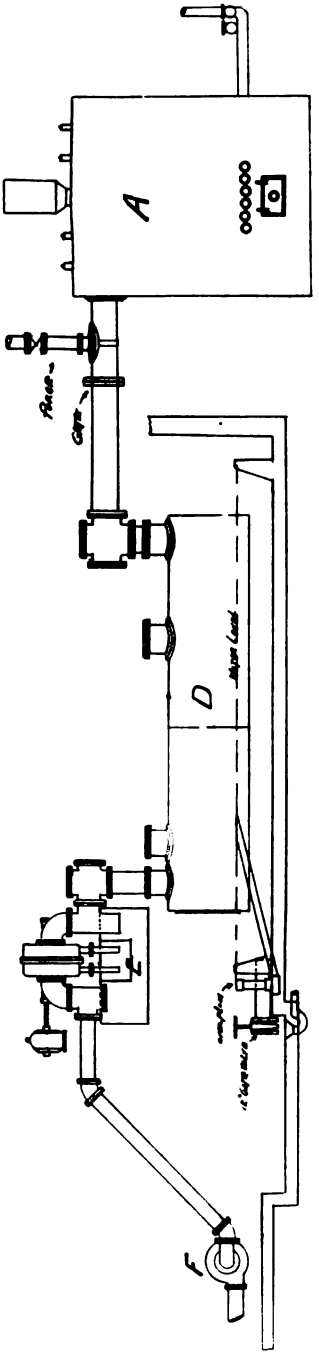

FIG. 2.—PRESENT ARRANGEMENT OF GAS CLEANING APPARATUS.

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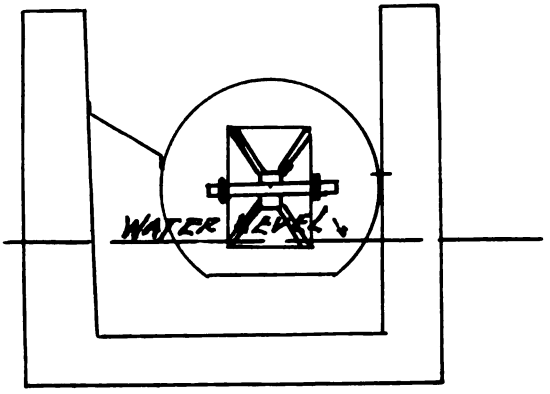

FIG. 3.—PRESENT ARRANGEMENT OF HYDRAULIC MAIN.

The gas generated by this type of producer contains more or less soot in suspension, which is precipitated by a drop in temperature or a change in velocity or direction of the gas. Scrapers have to be manipulated three times a day to keep the connection between the producer and hydraulic main open. There seems to be an inherent desire on the part of all operators to "poke down" the fire. This leaves "blow holes" in the fuel bed. The green coal, then charged, drops into these "hot spots," making a high quality gas, but as soon as this coal is volatilized, leaving the air free to blow through the holes, the quality of the gas drops far below the average. A series of tests, extending over a week, with samples drawn at intervals each day, shows that the gas quality fluctuated from 50 to 200 B. t. u. per cubic foot. The peculiar construction of this producer, Fig. 4, augments the tendency to form holes at the sides. To offset this, the cast iron ring was introduced. In addition, the petticoat or inner tile lining limits the depth of the fuel bed to four feet, including ashes. A deeper bed would aid considerably in making a uniform quality of gas.

To obtain the best results with this producer, the coal should be spread immediately after charging, as it has been conclusively demonstrated that this particular coal must not be disturbed after it once becomes hot. If a coke-crust overspreads the surface of the bed, preventing a free passage of gas, this crust should be broken up, inserting the poker to not more than 12 inches below the top of the bed.

A uniform quality gas means uniform operation, which is very much to be desired, even at the sacrifice of a few B. t. u. per cubic

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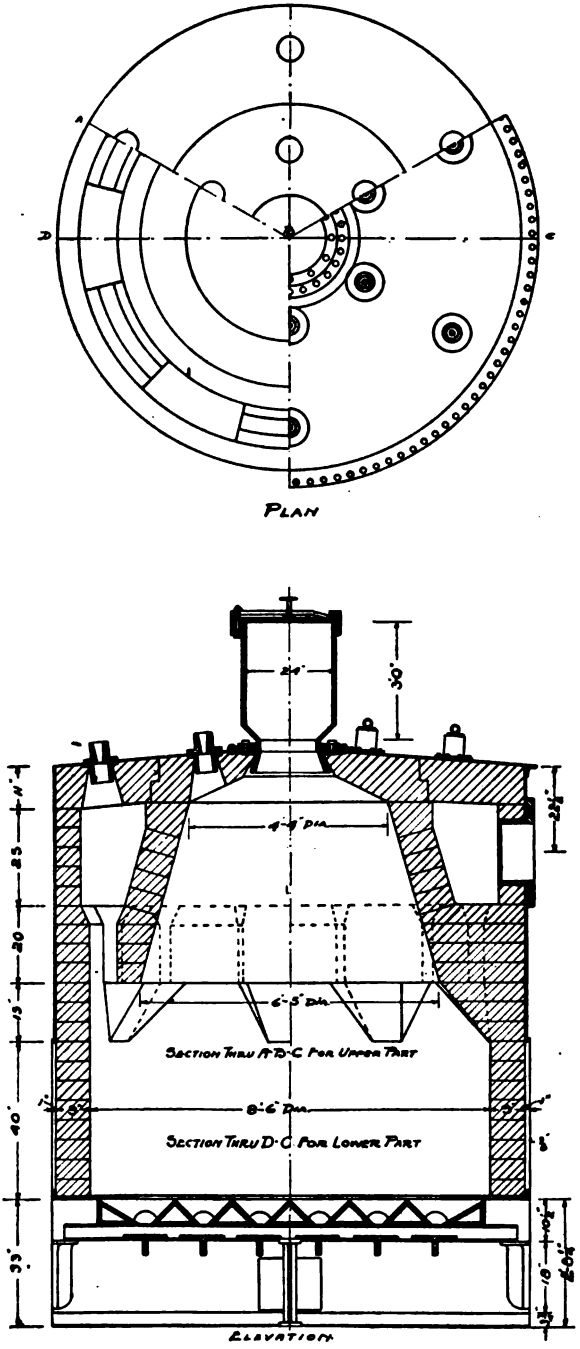

FIG. 4.—ASSEMBLED PRODUCER.

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foot. The thermal value of such a gas generated in this producer, with exhaust gas as the endothermic agent, and having the approximate analyses shown in Table I, would be about 100 B. t. u. per cubic foot.

TABLE I.

Analysis No. 1.		Analysis No. 2.	
CO_2	7.2 Parts.	CO_2	8.0 Parts.
Ill.	0.7 "	Ill.	0.3 "
O	0.3 "	O	0.3 "
CO	16.6 "	CO	15.8 "
CH_4	5.3 "	CH_4	5.4 "
H	4.8 "	H	4.5 "
N	65.1 "	N	65.7 "
	100.0 Parts.		100.0 Parts.

The hydraulic main serves as an accumulator, where the gas is partly cleaned and cooled by water sprays. The water runs to the sewer by an overflow, as shown in Fig. 3. The precipitated tar, mixed with soot, is unfit for commercial purposes and difficult to handle. However, the water from the Mississippi River, used for cooling purposes, contains a very fine sand, which, upon mixing intimately with the tar, robs it of its troublesome properties. The tar from the centrifugal extractor, treated with this sandy and muddy water, is thrown into the water seal of the hydraulic main, from which the entire accumulation of sooty tar and sand is washed away every two weeks. After the gas leaves the extractor it still carries tar in suspension, but is completely purged of soot. The amount of impurities in this gas runs as high as 0.066 grains per cubic foot. The governor valves on the engine show a heavy coating of tar at the end of two weeks, and, in fact, wherever the gas changes its direction or its velocity tar is deposited. The tar extractor is the main source of trouble, as a new rotor is required about every five months. The records show that since the changes described have been effected, the tar extractor gave out about May 1 and October 1, 1911, March 1, July 1, and September 30, 1912. The extractor in itself had not been changed.

The governor on the engine was originally connected up for a uniform quality of gas, varying only the quantity of mixture. The mixture of air and gas was to be regulated by hand. The variable gas quality made it necessary to alter this regulation, so that now the governor varies the mixture. In addition the sensitiveness of the springs in the governor was diminished to reduce the speed variation. When the governor rides near the top, the speed of the engine is about 132 r. p. m., and when riding near the bottom, but

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still within its range, the speed is about 120 r. p. m., giving an average of about 127 r. p. m. By means of a turn buckle in the rod from the governor arm to the governor valve shaft, the speed of the engine may be reduced to 80 r. p. m., a reduction of 47 r. p. m. This reduction in speed being effected by wire drawing of the gas increases the tar deposit and necessitates more frequent cleaning of the valves. Before the application of the turn buckle on the governor rod, operators frequently reduced the speed of the engine to 30 r. p. m. by throttling at the main gas valves, which, however, resulted in completely filling the six-inch pipe just in front of the valve with tar.

COMPRESSOR

The ammonia compressor frame proved too light for the strain, due to the increased speed. The result was that the crosshead and main bearing broke. One of the original cylinders also suffered an unfortunate accident, which occurred in the following manner. At the time of erection it was thought necessary to bring the gas engine up to speed before applying any load, and to do this the ammonia compressor was provided with a three-inch by-pass from the discharge pipe to the suction pipe under the stop valves, the idea being to start up the machine and then open the suction stop valves and close the by-pass. The machine had been shut down to repair a discharge valve spring, allowing air to enter the cylinder, and on starting up, for some reason, it had been permitted to run longer on the by-pass than usual. It is supposed that the mixture of oil, air and ammonia in the cylinder became too hot and exploded, resulting in a broken cylinder. Since then it has been demonstrated that it is possible and practical to start a gas engine slowly on compressed air, and that it is not necessary to bring the engine to full speed before "cracking" the suction valve. The by-pass is no longer used.

The present refrigerating machine is new throughout. The suction valves in the pistons have been modified; and, as the discharge valves had been very noisy, larger valves, somewhat altered, were substituted, eliminating the greater part of the noise. The suction valves in their improved form are much lighter but stronger, and make no noise whatever. Fig. 5 shows the action and construction of the valves.

The indicator cards, Fig. 6, were taken with a 16-pound indicator spring to magnify the difference between the suction pressure

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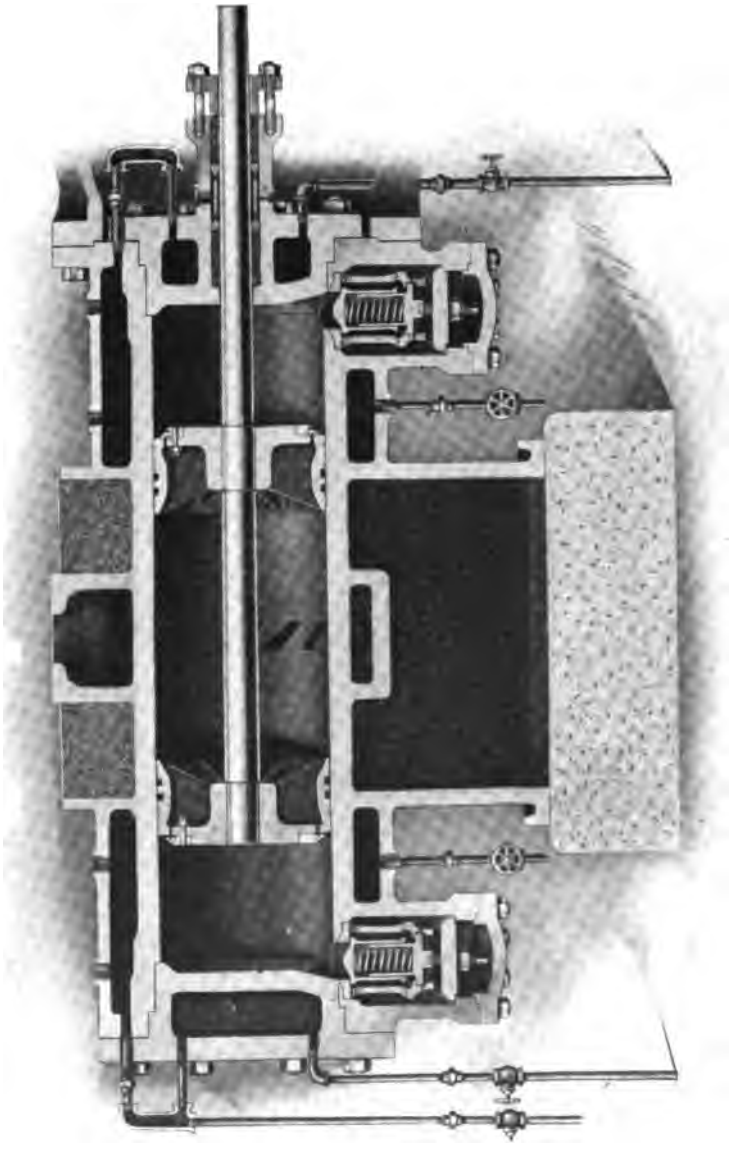

FIG. 5.—ACTION AND CONSTRUCTION OF REFRIGERATING MACHINE VALVES.

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in the cylinder and the pressure in the suction pipe. The temperatures of the discharge and suction gas at the time the cards were taken show some superheat in the suction gas. The cards show that the cylinder practically fills at suction pipe pressure at a speed of 130 revolutions per minute.

Referring to the cards, it will be noticed that the line produced by the suction pipe pressure is in the shape of an elongated figure eight laid on its side, thus ∞. This represents the condition which obtains in the suction pipe at different positions of the piston. The shape of the curve would indicate a certain amount of momentum to the gas at this velocity. It will be noticed that the cylinder pressure at the beginning of the suction stroke drops below the suction pipe pressure, but approaches it towards the end of the stroke. As the piston progresses the suction pipe pressure drops perceptibly, and it would seem that at this point where the decided drop in the suction pipe pressure takes place, the suction valve opens. As the cylinder pressure on the reverse stroke does not fall below the suction pipe pressure, the cylinder must have filled irrespective of any previous difference between suction pipe and cylinder pressure.

TEST

This gas-driven refrigerating plant has attracted attention for many reasons. Chief among these is its economical operation. The manufacturer of the gas engine and producer guaranteed under normal load a brake horsepower hour on not more than a pound and a half of coal of the same grade as that used under the boilers. To demonstrate this, indicator cards were taken and the horsepower calculated from the cards. After a week's run the engine had developed on an average 318 1/3 indicated horsepower, while the compressor indicated horsepower was 222.05, representing a combined mechanical efficiency of 69.7 per cent. It is assumed that the mechanical efficiency is equally divided—that is, 84.85 per cent. for each machine, making about 270 brake horsepower for the engine, which is about 75 per cent. normal load. The engine is 21 inches by 30 inches, two cylinder, tandem, double-acting. The results show an average coal consumption of only 1.54 pounds per brake horsepower hour.

The following test was conducted to find out how many tons of ice per ton of coal it was possible to produce under the circumstances with the engine operating at normal load:

The cooling water was cut down to raise the condenser pressure,

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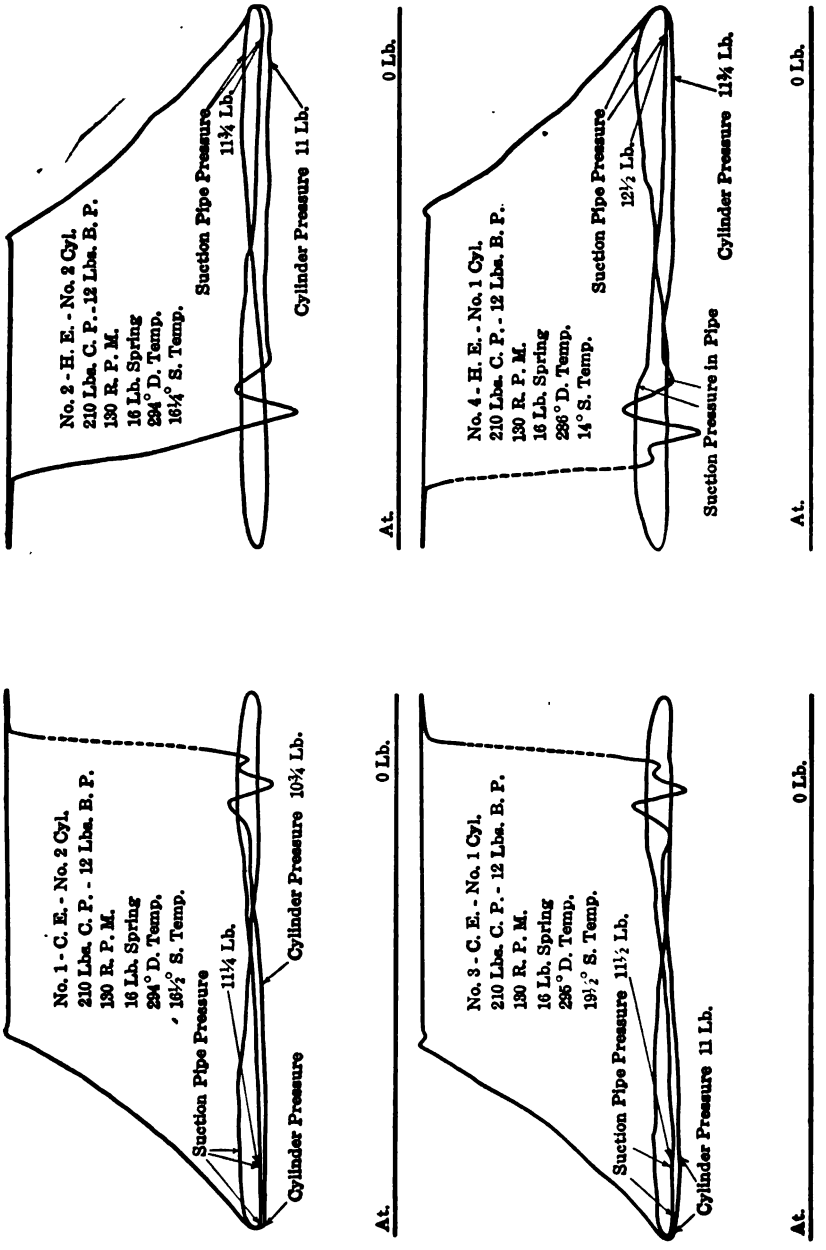

FIG. 6.—INDICATOR CARDS FROM AMMONIA COMPRESSOR, MAGNIFYING THE DIFFERENCE BETWEEN THE SUCTION PRESSURE IN THE CYLINDER AND THE PRESSURE IN THE SUCTION PIPE.

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but the water valve had to be frequently shaken to keep it from stopping up on account of mud and dirt in the water, and the result was a more or less variable condenser pressure. While the horsepower fell short of the normal rating, the results obtained were considered sufficiently interesting from a refrigerating standpoint to warrant their being submitted to the Society. The test was simply a commercial run; readings were plotted from the regular engine room log, taken every three hours. There was nothing exceptional about the run, other than to try to hold a high condenser pressure.

To make clear why it is not possible to run a test on this plant under favorable conditions at any time, it would be well at the outset to call attention to the nature of the service. The compression refrigerating machine is cross-connected with two other compression refrigerating machines, which together handle the ammonia for cooling the "high brines" (12 degrees Fahr.) for two distinct systems; two low brines (—12 degrees Fahr.) for two distinct systems and an ice tank, which is expected to produce 816 four-hundred pound cakes of ice per day. These cross-connections are so made that the shutting down of any machine will not entirely stop the work on any of the five loads.

In order to obtain fairly accurate results, it would be necessary to put the gas-engine-driven refrigerating machine on the ice tanks, thereby diminishing the load and either reducing the speed of both of the remaining refrigerating machines, or stopping one altogether and speeding up the other. The opportunity presented itself when one of the other refrigerating machines was temporarily shut down for repairs. The unit to be tested was put to work on the ice tanks.

Fig. 7 shows the temperatures at the beginning and at the close of the test, which started at 9 o'clock A. M., November 30, and stopped at 9 o'clock A. M., December 6. 1911. The amount of cooling water on the distilled water cooling coils was not varied and the temperature of the distilled water passing to the forecooler averaged 53 degrees Fahr., varying from 50 to 55 degrees. These temperatures are not recorded on the engine room log. The condenser and suction pressures were held constant with more or less success. The ice pullers were instructed to pull 600 cakes daily except Sunday, when they pulled 352 cakes in half a day.

The level of the fuel bed in the producer was held at the same height throughout the test, and the coal bunker filled to the same mark every morning and weighed. All coal in this plant is weighed every morning. The ashes were weighed dry. Fig. 8 shows the

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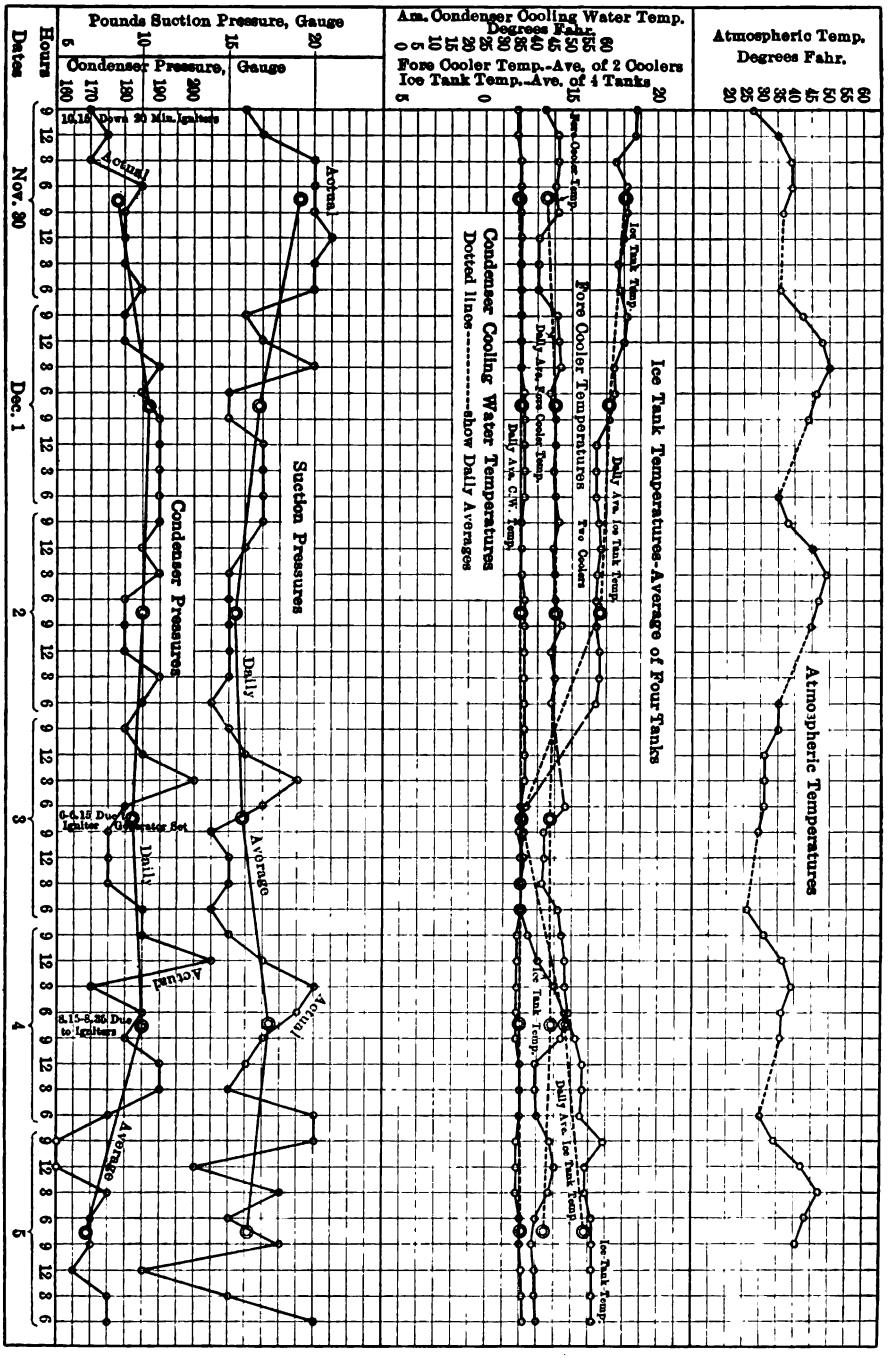
Atmospheric Temp. Degrees Fahr.
Atmospheric Temperatures
Am. Condenser Cooling Water Temp. Degrees Fahr.
Fore Cooler Temp.--Ave. of 2 Coolers
Ice Tank Temp.--Ave. of 4 Tanks
Ice Tank Temperatures-Average of Four Tanks
Fore Cooler Temperatures
Two Coolers
Condenser Cooling Water Temperatures
Dotted lines----------show Daily Averages
Pounds Suction Pressure, Gauge
Condenser Pressure, Gauge
Suction Pressures
Condenser Pressures
Actual
Average
Daily
10.15 Down 20 Min. Igniters
6-6.15 Due to Igniter Operator Set
8.15-8.30 Due to Igniters
Hours
Dates
Nov. 30
Dec. 1
2
3
4
5

Fig. 7.

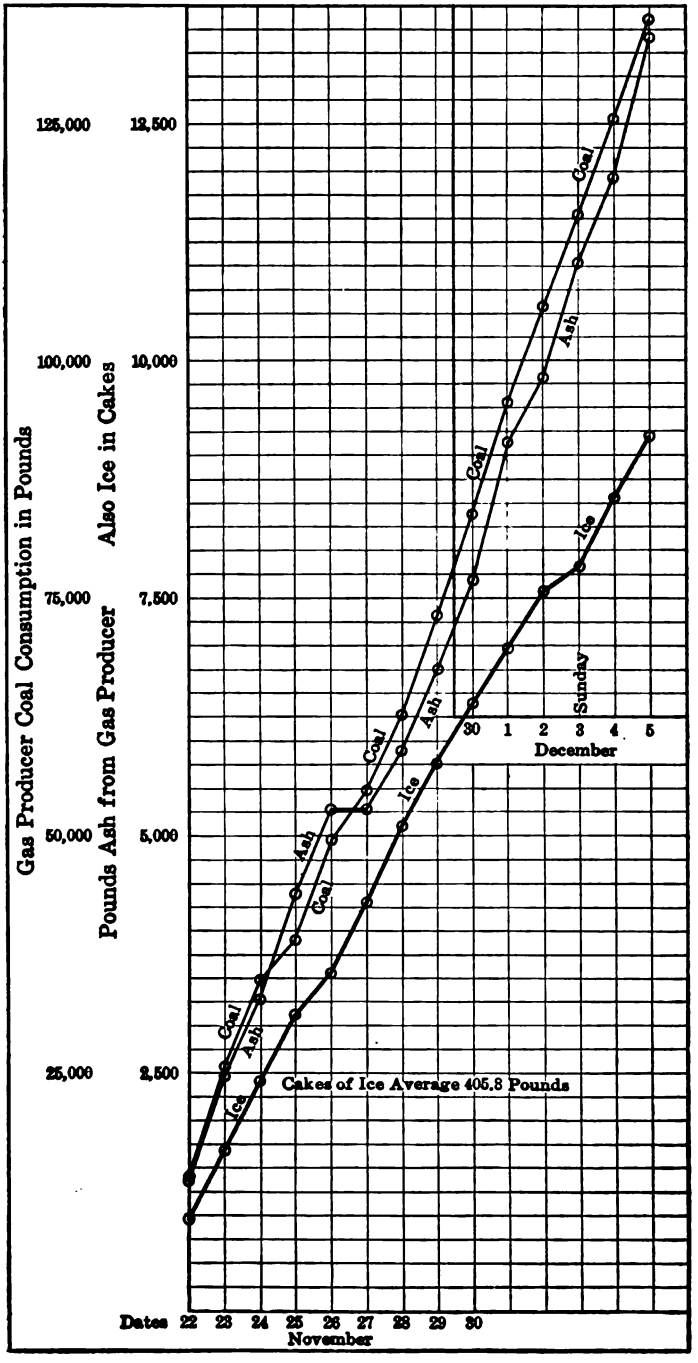

FIG. 8.

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amount of coal fired each day from November 22 to December 5, 1911, and that there was practically no difference between the daily charges of coal before and during the test.

The test lasted six days or 144 hours. There were three stops, one for 15 minutes and two for 20 minutes, a total of 55 minutes, leaving 8,585 minutes of actual running time. The total number of revolutions as shown by a recorder was 993,076, or an average of 115.68 revolutions per minute.

The cubic inch displacement per revolution of the compressor is 12,930.96 and per minute would be 1,495,853.45 cubic inches.

The total amount of ice pulled was 3,425 cakes, weighing on an average 405.8 pounds, making 115.8 tons per day of 24 hours. This would give 12,918 cubic inches displacement per minute for a ton of ice per day. The ice tank contains 1,632 cans, which makes the rate of freezing per cake about 68 2/3 hours.

The results of the test are partially summarized in Table II.

TABLE II.—SUMMARY

Duration of test, hours	144
Total amount of ice pulled, cakes	3,425
Average weight of cakes for six days, pounds	405.8
Total weight of ice pulled, tons	694.9
Average amount of ice per day, tons	115.8
Total coal consumption, pounds	62,900.0
Total coal consumption, tons	31.45
Average coal consumption per day, tons	5.24
Total ashes, pounds	6,650.0
Average ashes per day, pounds	1,108.4
Ash in coal, per cent	10.6
Ice per ton of coal, as fired, tons	22.10

Three approximate analyses of coal are given to indicate the character of the coal, which is washed Illinois bituminous of about such size as will pass through a one and one-fourth inch mesh, but be retained on a three-fourths inch mesh.

TABLE III.—ANALYSES OF COAL

	No. 1, Parts.	No. 2, Parts.	No. 3, Parts.
Moisture	7.83	6.22	9.58
Vol. matter	38.11	44.15	39.77
Fixed carbon	42.00	43.00	41.33
Ash	12.17	6.63	9.32
Sulphur	3.31	2.81	2.68
B.t.u. per pound	10,871.	11,342.	10,872.

It is impossible to accurately determine the coal consumption for each of the auxiliaries, but the approximate consumption was arrived at as follows:

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Wattmeters were placed in circuit with the motors driving the ice tank agitators, the tar extractor and ignitor generator on the engine. The amount of water circulated for cooling the gas engine and compressor jackets was measured by a water meter which indicated 7.5 cubic feet per minute. The temperature of the water to the compressor and gas engine was 52 degrees Fahr. The water left the gas engine at an average temperature of 108 degrees and the compressor at an average temperature of 61 degrees Fahr. This water is pumped against a head of 110 feet, including friction. Assuming 50 per cent. for the combined efficiency of pump and motor, the horsepower would be 3.13. Estimated in a like manner, 0.25 horsepower was required for the circulation of the oil. The water used on the distilled water cooling coils and condenser coils averaged 163.3 gallons per minute against a total head of 115 feet, requiring 9.51 horsepower. To pump the distilled water against a head of 112 feet requires 1.15 horsepower. To compress the air for ice hoisting and starting requires about 5.75 horsepower. The power consumed by auxiliaries is summarized in Table IV.

TABLE IV.—POWER CONSUMED BY AUXILIARIES, ESTIMATED

	Horsepower.
Driving icetank agitators	21.24
Driving tar extractor and ignitor generator	17.41
Circulating jacket cooling water	3.13
Circulating oil in lubricating system	0.25
Pumping water for condenser and cooling coils	9.51
Pumping distilled water	1.15
Furnishing compressed air for hoisting and starting	5.75
Total	58.44

Assuming 1.81 pounds of coal per horsepower hour, including an allowance for transmission from engine to motor, would give a coal consumption for auxiliaries of 58.44×1.81 pounds, or 2,540 pounds (1.275 tons) per day. Including auxiliaries, the total coal consumption on the above assumptions would be 5.24 tons plus 1.27 tons, or 6.51 tons per day.

The ice per ton of coal as fired:

$$\frac{115.8}{6.51} = 17.8 \text{ tons.}$$

Summer conditions would call for more water on the ammonia condenser, as the temperature of the water at that season is often as high as 88 degrees Fahr., and the temperature of distilled water

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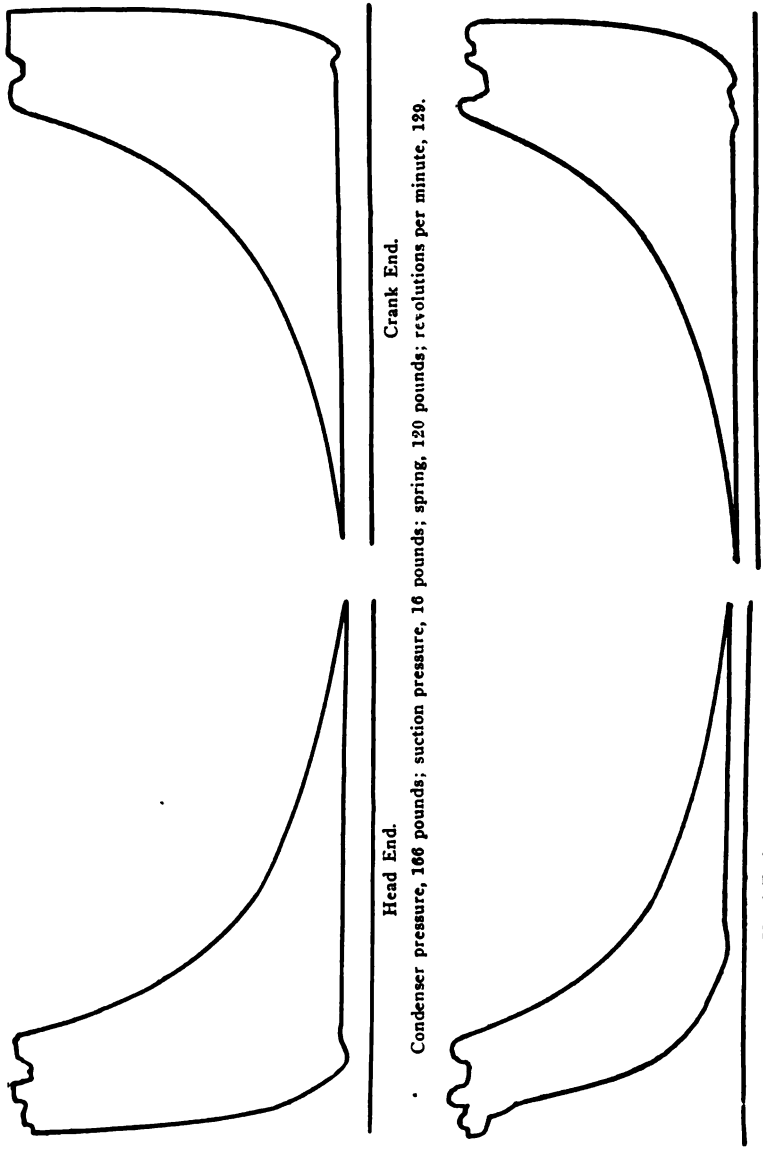

FIG. 9.—AMMONIA COMPRESSOR INDICATOR CARDS, TAKEN AFTER TEST.

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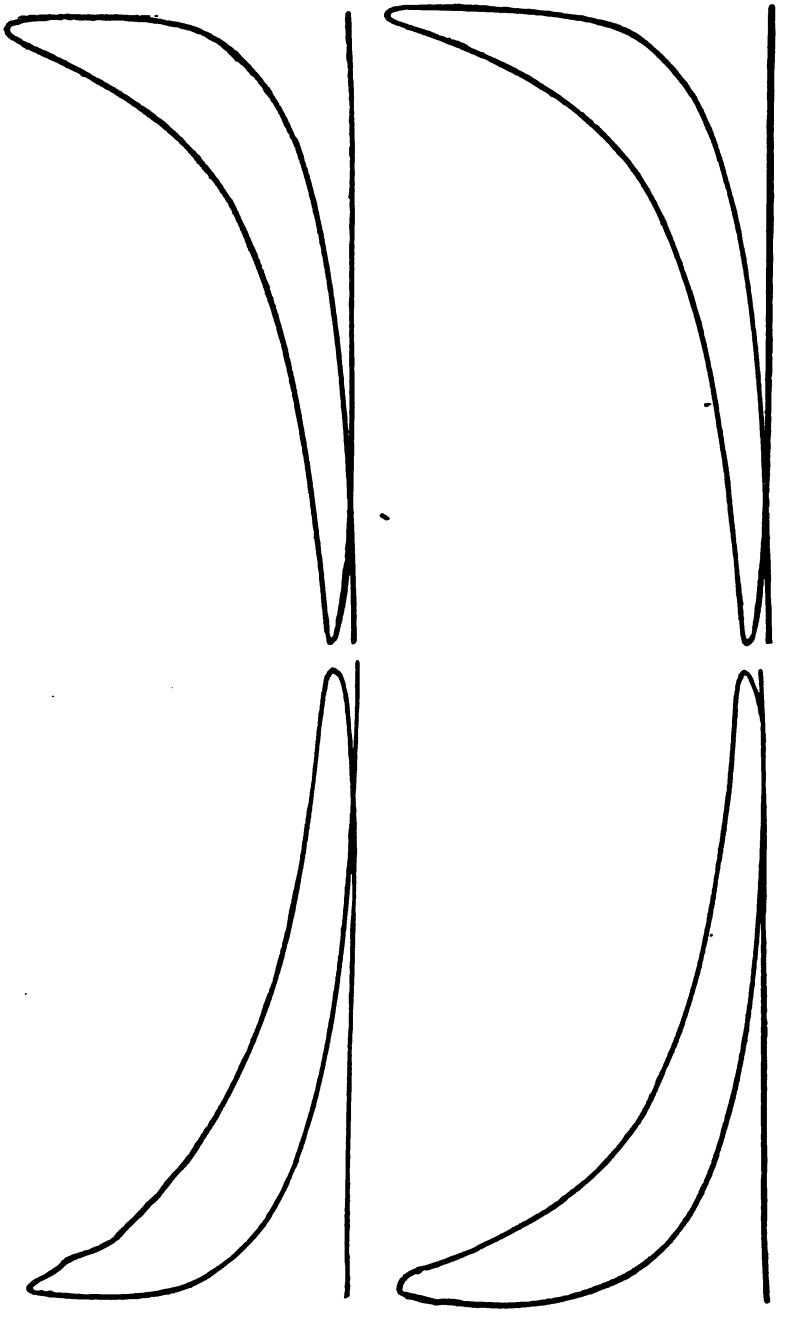

Scale, 150 pounds; head pressure, 200 pounds; back pressure, 19 pounds.

FIG. 10.—GAS ENGINE INDICATOR CARDS, TAKEN AFTER TEST.

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to forecooler as high as 96 degrees Fahr. The temperature of the atmosphere would average for the hot months about 79 degrees.

The indicator cards of both compressor, Fig. 9, and gas engine, Fig. 10, were taken several days after the test, and are submitted to show the action of the machines. One of the compressor cards taken on December 9 shows the effect of a broken discharge valve spring.

The cooling water from the ammonia condenser is used in the gas-cleaning apparatus and is ample for the purpose, but the tar and impurities taken up make the water unfit for use in a cooling tower. Where water is obtained under difficulties and at a considerable cost, a plant of this arrangement would be prohibitive.

With the exception of the tar extractor, the installation has given good service throughout the summer. The shut-downs, as shown on the record for 183 days, from April 1 to October 1, 1912, are given in Table V.

TABLE V.—SHUT-DOWNS

	Hours.	Minutes.
Due to tar extractor	51	25
Fourteen Sundays	49	..
Due to producer, engine or compressor	32	5
Total	132	30

A short time ago the writer was asked to visit a plant in which an extractor, without movable parts, extracts tar from producer gas without the use of water. It employs only sufficient steam to keep the tar in a liquid state. This extractor has been giving excellent results for the last three months, furnishing gas which will permit of throttling at the main gas valve without serious deposit of tar. A gas plant provided with this type of extractor would be as flexible as a steam plant.

DISCUSSION

Peter Neff.—I have not had time to go through this paper and examine the report of the test run, but the subject is very interesting to me personally and I wish to call your attention to two things. You notice they use soft coal and its B. t. u. value is vastly different from that of hard coal, so in the performance of the engines you must make certain corrections according to the value of the coal if you are figuring for this locality. The writer shows here that the value of the coal in three different tests is just under 11,000 B. t. u. per pound, whereas Eastern hard coal runs about 13,000, if I remember rightly, so that the performance here should be based on that

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valuation of the coal. There are two places in which he gives the number of tons of ice produced and tons of coal consumed, and they vary. In the first case, you will understand, only the compressor and engine are taken into consideration, while the other takes in the auxiliaries which derive their power from other sources than the gas producer, the coal consumption of which he has estimated. There is one other point—I am sorry that Mr. Gallenkamp is not here, for I should like to hear him discuss it—and that is what he has allowed as the mechanical efficiency of the two parts of the apparatus.

You will notice that he has divided the friction load equally between the compressor and the engine. I should like to know whether, since that time, he has made any tests to show whether he was right in that assumption or not. The installation, as originally put in, suffered a good many drawbacks, the principal one came from the producer end, as he has shown here, and that transferred itself to other parts of the apparatus in this way: The producer was to deliver gas under certain pressure at the engine, but it did not do so regularly. The result was that the engine would lie down from time to time and the valves on the compressor would be immediately closed to allow the engine to gather headway again. I have seen several instances when the suction valves would be opened wide with a suction pressure of twenty pounds and the engine would go to full speed. That occasions a shock and jar that is rather unusual. The strains at those high velocities are different from those of ordinary practice, but they have all been overcome. The hardest problem we have is that of the large coil spring in the discharge valve. They have given a good deal of trouble until this year, when we got chrome vanadium steel for those springs, which has increased their life very materially.

President Shipley.—In your opinion, where should the division of loss be made between the engine and the compressor?

Peter Neff.—I do not think, personally, that the writer is fair in dividing it equally. I cannot help but feel that the engine, from my knowledge of the units, should be charged with more loss than the compressor, but I should like very much to see tests made. When you look at one of these engines and see the gearing and lifting of the valves and all that has to be done in the way of dead work, and compare that with the compression side, it does not look reasonable on the face of it.

President Shipley.—Would you mind telling us whether you be-

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lieve the best method of installation is a gas engine direct connected to a compressor, or would it be better to connect the gas engine up to an electric generator and drive the compressor by an electric motor?

Peter Neff.—I feel in this just as I do about high-speed engines and internal combustion engines. The internal combustion engine with high-speed compressor is coming, and the sooner we face the problems, the better. For the time being we are going to have troubles; many of them have already been overcome and others are being overcome daily, and I cannot help but feel that the machine of the future is the direct connected unit, but it is going to take time to develop it. It is a shock to the ordinary man to talk to him about it; it looks bad, but when you go into any engine room and see a slow-running compressor and right alongside of it a high-speed, direct-connected generator set, the question arises, which gives the most trouble and which is the best practice? One runs about as smoothly as the other. The high-speed compressor is coming and, since the direct connected unit reduces the friction, it will be the design ultimately adopted.

President Shipley.—Don't you think, Mr. Neff, that the principal difficulty in such an installation is the very thing he speaks of here, the necessity of running the machine with a by-pass or taking chances?

Peter Neff.—The question of that by-pass is interesting; as he says in his paper, when that installation was first proposed it was thought impossible to start the unit without releasing the load in some way. The only logical way to do it was to put a full-sized by-pass between the suction and the discharge valve, but about the only time it was ever used was the time when they had the explosion he refers to. They had had the compressor open, and, in starting up, thought they would try it to see if the engine would start any easier. The result was that the centre part of that compressor was blown all into little bits. Both ends, where the compression takes place, stayed right there. The explosion took place in the suction chamber. They had both the suction and discharge valves shut and the by-pass wide open; they had the cylinder full of air, and the mixture, in some way, caused this explosion, which is not an unknown phenomenon. They don't use the by-passes now and had not been using them commonly before that. The compressed air used to start the engine gives a sufficient kick-over to start the load.

President Shipley.—You have had considerable experience

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coupling up these machines, direct and indirect. Which do you think is better with the gas engine?

Peter Neff.—I would have to know the conditions.

President Shipley.—Suppose you had the laying out of a plant?

Peter Neff.—In laying out a plant I would advise both.

President Shipley.—You would take a chance on both?

Peter Neff.—I would take a chance on the direct connected.

President Shipley.—On the level, now?

Peter Neff.—Yes, but you can't make a purchaser believe that, so what is the use of trying to force it on him when he is not quite ready for it. I might say that in this plant the reason for its installation was a peculiar one. They had only a limited amount of room and they were forced, they thought, because of that limited room, to put in a gas engine. When they came to figure on the question of transmitting the power from the gas engine to the compressor they were met by the fact that their space was still too limited, and to belt back was impracticable, so they were obliged to figure on a geared connection. The experience with geared connections was not very satisfactory, and that led to taking up direct connection. This was a great step in advance, but one which the ordinary trade of to-day is not prepared to take, so that in most cases where they are using gas engines we figure on belt-drives. Now the trade is not ready for these immense strides forward, but just as sure as we are here, it is going to come sooner or later, and this installation has served as a guide in that direction. But you must bear in mind one thing about this gas engine business, that the producer is the heart and lungs of the whole system, and when the producer gives you trouble, you are down and out, and the soft coal producer has not reached a high degree of perfection. The hard coal producer seems to get along pretty comfortably, but, just as he says in this paper, when you change the temperature or check the flow of gas, it begins depositing tar. Both the Government and individuals are working hard on the question of the producer, not only for burning soft coal, but for utilizing that vast deposit of lignite that underlies all our far West and from which ultimately the power of that country will be derived.

President Shipley.—Mr. Block, could you tell us something about the installation of gas engines?

Louis Block.—If you have a compressor which can be driven at the same speed as the internal combustion engine, it seems to me that it is the simplest thing to drive direct; if you haven't, then I

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should say that the next best thing would be to use a clutch on the main shaft of the gas engine, starting up your gas engine, throwing in your clutch afterwards, and driving by belt. Belt men, as a rule, will tell you that if you want to transmit 175 or 200 horse-power you must have a belt 38 inches wide and 40 feet between driving and driven centers. That is not true. I have a plant in mind now, the Anheuser-Busch Bronx Agency plant, New York City, described in Cold Storage and Ice Trade Journal, July, 1912, where the distance between the Diesel engine shaft and the compressor shaft is only 15 feet; the compressor is 17¼ by 34, and, at the suction pressure under which it usually operates, does about 110 tons of refrigeration with about 175 horse-power. The belt is only 24 inches wide. The driven belt wheel is 14 feet in diameter and the driving wheel is 56 inches, and it runs very comfortably; so these great distances and this great space which it was thought necessary is, in reality, not necessary.

There are, in the natural gas belts, a large number of gas engines direct connected to gas compressors, compressing up to as high as 300 pounds. A number of failures have been recorded. A single-acting, four-cycle gas engine connected in tandem to a gas compressor was an absolute failure. It was to run at about 80 or 90 revolutions, but couldn't run more than fifteen minutes without having the piston stuck in the motor cylinder. The reason for this was that the engine piston had, in this case, to serve as crosshead, but was not so designed. It had to move the compressor piston, which was fastened to the extended gas engine piston rod, which passed through the engine cylinder head. The company, which was a very large one, fooled with it for a long time, but had finally to take it out. If it is desired to connect compressors direct to a gas engine, I should say connect the compressor on the same shaft. If the engine is a four-cycle, single-acting engine, don't connect it in tandem to a compressor. If it is a two-cycle, double-acting engine, and if your compressor is so designed that it can run at the speed of the gas engine, I don't think there should be any trouble.

President Shipley.—In regard to that short belt centre proposition—do you use a belt tightener, Mr. Block?

Louis Block.—No, not a belt tightener, only an idler to take up the shock due to the reciprocal motion of the compressor, and the fact that the great exertion is made at the end of each sroke, which would otherwise bring about a flopping of the belt. I put an idler exactly midway between the driving and driven shaft, which may

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give me slightly increased belt contact, but it is not the Lenix drive for increasing belt contact; it is simply to prevent that flopping motion of the belt.

President Shipley.—In this particular case that we are discussing, Mr. Neff, where does the distilled water come from?

Peter Neff.—Ordinarily from the engine of a compression machine and from the generator of an absorption machine. They have in that plant, as you possibly know, two large, vertical compressors and also an absorption system. They not only run a cold storage and ice-making plant, but handle a street line as well, and many of their auxiliaries are steam-driven, so they have a good deal of exhaust steam.

President Shipley.—I wanted to bring that out so there could be a better understanding for comparison. Can anybody give us any further information in regard to the possibilities of a gas engine driven ice plant?

Louis Block.—I think we ought to wait until the gas engine, and especially the producer, is better developed, before we go into it to any great extent. The soft coal producer gives us a great deal of trouble on account of the tar. Mr. Gallenkamp says he has found a means of curing it, and there is another extractor in which steam is used for the purpose of keeping the tar in a fluid state. I suppose he takes it out in connection with baffle plates of some sort, but the tar, while it is a valuable product and contains a large number of heat units that could be very well used in the gas engine, gives so much trouble that we must extract it. I have found accidentally that tar precipitates if the gas is compressed only slightly, and it seems to me that if somebody would go into that and compress the gas—it would be a waste of power, of course, but you have to do something in order to get rid of the tar—compress it to a few pounds' pressure and then pass the gas over baffle plates for further security, all the tar would be precipitated. About ten years ago there was exactly the same talk as to-day: "Oh, we will soon perfect the gas producer to such an extent that it will not give us any trouble; we will have continuous, uninterrupted working and have no tar." We are in exactly the same position to-day, although you will find hundreds of patents for producers. The hard coal producer gives us enough trouble, but the soft coal producer gives us no end of trouble. The Government is doing all it can to help us, and extensive tests have been made, as you know, but still the whole apparatus is one we will adopt only if we are compelled. Until that

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time I think we will stick to oil, if we want a good combustion engine, as the simplest proposition.

Peter Neff.—I just want to add that the natural gas field covers a large part of our western territory.

President Shipley.—Mr. Block has hit upon a subject that I tried to touch upon in my alleged address. I seriously question the advisability of putting gas engines, with their inherent troubles, in ice plants, simply for the purpose of saving a few dollars in fuel. I had occasion to make a few kind remarks about gas engines and gas producers down in Washington a few years ago, and lost a big contract by reason of it, because I wouldn't agree with an engineer who was advocating gas engines for a plant—not only gas engines, but a gas engine to drive each compressor by rope transmission, and there was another ingredient in the dose, and that was bituminous coal gas producers. That looked too tough for me, and I had to come out and tell them where I stood. I did not mind taking chances singly, but I objected to them in bunches, and we lost a job. I advised them if they were going to do anything like that to take the lesser of the two evils, put in an anthracite producer, which we knew something about, and which would give us a reasonable quality of gas, and then produce electricity and drive the compressor with a motor, but I was poo-hooed, and some other fellow took the job.

Well, it took them a year before they got any ice out of that plant, and when I was down there a few months ago I found out that the addition to the plant was connected up in exact accordance with the advice I gave them for their original installation. This was to put in a generator, driven by a gas engine, and to drive the compressor by a motor. I also found that they had torn out their bituminous producers and put in anthracite producers. Some one had paid for the chances taken on that plant. I don't mind losing a job like that. I believe we ought to go a little bit slow on those things. I believe when we stop to figure up what we really save at the end of a year or two we would not take so many chances. Freak plants are not money-makers for the man that puts them in or the man that buys them.

Louis Block.—The greatest flexibility with a plant of that kind can be obtained if you drive generators either direct connected or otherwise, then send your current to a switchboard and from the switchboard to motors, which, in turn, drive the refrigerating machines by belt. If you have two refrigerating machines to drive, take three gas engines and have all three direct connected to the

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generator producing your current. I don't think I would ever undertake to build a plant with just one gas engine and one refrigerating machine, or two gas engines and two refrigerating machines; I want an extra gas engine.

Theodore Kolischer.—But isn't that rather costly?

Louis Block.—It is.

Theodore Kolischer.—And there are very few purchasers who would be inclined to spend the money, even if you should succeed in convincing them of its merits. Isn't that a fact?

Louis Block.—I believe it is.

Theodore Kolischer.—We are up against the low price of ice and the tendency to economize in the cost of production. We meet that every day on the "firing line," as the President has termed it, and something has to be offered against the old, simple plant that would produce six, seven, or, possibly, eight tons of ice per ton of coal, and while the gas-producing engine is the best thing we have, even with all the troubles you have so ably illustrated, we still hesitate to recommend it.

Louis Block.—That is just my opinion.

Theodore Kolischer.—And stick to the old?

Louis Block.—For some time to come.

Theodore Kolischer.—But the general complaint is that they cannot make any money, with coal at $2.00 or $2.25 in this section of the country, producing six or seven tons of ice on the platform per ton of coal. This is a matter that is very easily calculated, and leaves almost no profit to the ice manufacturer, so we are "between the devil and the deep sea."

Peter Neff.—I cannot let this opportunity go without saying one word more about this gas engine business. Mr. Block has expressed himself as believing there should be two units; that, I think, is more applicable nowadays to a producer or oil engine than it is out in our country, where we have natural gas. I was very much opposed to gas engines, but we have now gotten gas engines working with natural gas so that they work day in and day out and give no more trouble than a steam engine. That condition you don't meet here in the East, of course, but we have it out West, and plants are going in continually to be operated by natural gas, which is the ideal fuel to be used directly in internal combustion engines.

Louis Block.—What I said did not refer to natural gas engines. Of course, they are a simple and economical means for producing power. So is the ordinary gas engine run on illu-

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minating gas a simple proposition, but it is too expensive. What I said only referred to producer gas, nothing else.

Charles H. Herter.—With reference to the mechanical efficiency to be ascribed to the gas engine, tests on similar engines have shown this to be between 75 and 85%, as against 84 to 85% assumed by Mr. Gallenkamp. At only three-quarter load, as in the test described, the efficiency is not likely to exceed 82%, thus leaving the difference, about 3%, to be credited to the compressor. I should like to know whether the 405.8 pounds given in the paper as the average weight of the blocks of ice represents their weight before or after thawing from cans.

Frederick L. Pryor.—In regard to oil engines, I know that there are now some that will stand a long service without shutdown. I had occasion to test a 150 horse-power engine in Pennsylvania, which had been running for five months without a shutdown, except for an hour each Sunday. The engine belonged to the Standard Oil Company and was used for pumping oil. By using this engine they were able to shut down the steam engines. I believe the oil engine is a very substantial prime mover.

President Shipley.—What are we going to do now, since the Standard Oil Company has refused to sell us fuel oil? That is a question we have got to face in connection with this oil proposition. The Standard Oil Company has sent out a notice that they will not sell fuel oil after the 1st of December. It hits us fellows hard who are working our shops with fuel oil. It means a raise in the price of oil for fuel, even if we can get it.

W. H. Dohrmann.—Just for a point of information in regard to the use of oil engines and gas engines—it might work successfully on plate plants, but what are we going to do on a distilled water can system? Wouldn't the cost of evaporated, distilled water offset the saving on the other end?

President Shipley.—That's why we have been trying to develop the raw water plants to take the place of the distilled water ice plants. If we can make raw water ice in cans, then we can use the gas engine in can plants; otherwise we must complicate our plants by putting in evaporator systems to produce distilled water.

W. H. Dohrmann.—What I want to know is, in the operation of the evaporating system, wouldn't that take off a great deal of the economy—wouldn't that reduce the saving?

President Shipley.—That's a question. There is both interest and wear and tear to be considered.

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F. W. Pilsbry.—In evaporator plants operated in Chicago we have found that the fuel cost to operate the evaporators is 13c per ton of ice made. To this cost must be added the cost of upkeep.

President Shipley.—The plants Mr. Pilsbry speaks of are driven by electricity. The evaporators are used to supply all the water to fill the cans.

Theodore Kolischer.—I notice that the author of this paper refers in one place to 22 tons of ice per ton of coal burned, and in another to about 17, including the auxiliaries. I know of another plant not very far away, a raw water plant, which has been operated this summer for about three months with a producer gas engine, and it has produced 35 tons of ice with 2,520 pounds of anthracite coal. That was the average for about 60 days. The engine operated satisfactorily for about 72 days, without a shutdown of over half an hour or an hour. How long it will operate next year I cannot say, but those are facts that I can vouch for.

Peter Neff.—That includes the auxiliaries?

Theodore Kolischer.—Yes, everything. It includes every blessed thing on the plant.

Peter Neff.—What was the heat value of the coal?

Theodore Kolischer.—I don't know, but I should judge about 13,000 or a little over.

Louis Block.—Where did it come from?

Theodore Kolischer.—The Lopez Mine, in Pennsylvania: it is a sort of a cross between anthracite and soft coal, but it is recommended by the people who built these gas engines as the coal best suited to the producer. It is small-sized coal, I should say between a nut and a buckwheat.

Peter Neff.—According to your statement that the heat value was 13,000, it would be only about 33 1-3% more than they are getting out West, which would bring the production up to about 26 tons. It is probably nearer 15,000, or 50% more than the coal they are using out there, and that was the very point I tried to bring out when I first started to talk, that you people down here always base your ideas and calculations on hard coal, whereas the poor fellows out West, where the coal is, as a rule, below 9,000, have to work on that basis. The test that he shows here is exceptionally good Western coal, and the results are very satisfactory, and about compare with what you give.

Theodore Kolischer.—But we must take into consideration the district in which we are working. We here in the Eastern section

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of the country, blessed with anthracite coal, are probably at better advantage to operate these plants than you in the West.

Peter Neff.—I agree with you, but you should not take your standards and set them up against ours without clearly showing where the difference lies.

R. E. Bridgette.—In regard to the coal Mr. Kolischer spoke of, it is about 14,450. I would like to ask Mr. Kolischer if that was a can or a plate plant.

Theodore Kolischer.—A can plant.

R. E. Bridgette.—Did that include the coal burned to get condensed water, or did you use raw water?

Theodore Kolischer.—Raw water, but it included all the auxiliaries; every one.

John L. Plock.—In looking over this paper I see that while it shows they have made a great deal of ice per ton of coal, at the same time, if the purpose of this paper is other than that of describing a gas engine driven compressor, I mean that if the object is to show the increased quantity of ice made possible by the use of producer gas engine drive, in my opinion this paper has not gone far enough, and it it is not a fair comparison, inasmuch as there are no charges against the plant for repairs, depreciation, etc., which we know must be taken into account when figuring the cost of manufacturing ice. Here I notice they stopped about five days in seven months; that to an ice manufacturer, especially if it occurred during the period from April to October, would be a serious matter and amount to a considerable loss. Again, the fixed charges against the average gas engine producer plant are very high, and while I think we will eventually come to the internal combustion engine, the best thing we have got to-day to meet all condition of compressor drive is the oil engine, especially of the "Diesel" type.

President Shipley.—I don't think we can consider this paper for any other purpose than as a discussion of a gas engine driven compressor. I don't think the writer intended it to be anything else. He only gave us the information about the ice production of the plant incidentally. I think, Mr. Neff, that this paper was not written for any other purpose than just to give us information about the operation of the compressor driven by the gas engine, and to supplement the paper Mr. Tait wrote on the same plant a couple of years ago. The paper we are discussing shows us the improvements that have been made since Mr. Tait read his paper.

Peter Neff.—I think so.

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President Shipley.—On the plant we are discussing there is a can allowance that we cannot afford to use—68-hour ice. They ought to be able to knock the spots out of things making 68-hour ice. The author has given these data so that you can figure it out for yourself, and I believe this paper is entirely fair in that regard. So far as making ice is concerned, there are lots of producer plants making 25 tons of ice per ton of anthracite coal. We have installed a number of them, but they have their troubles. That's what I want to bring out. You can't expect to get something for nothing. If you are chasing the coal pile, you have to pay for it all right; you can't expect to succeed by putting your plants in the hands of any one but competent men, and you must use proper coal; that your upkeep is going to be increased goes without saying; so if your coal is such an item that you are willing to invest the money to reduce this item to a minimum, you must expect to have plants that are more complicated and that require a higher class of men to operate.

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No. 102

AVOIDABLE ACCIDENTS IN REFRIGERATING PLANTS

By Louis Block, New York, N. Y.

(Member of the Society)

It is the custom, and a very laudable one, to test ammonia piping with air pressures of from two hundred and fifty to three hundred pounds per square inch before charging the system with ammonia. The inexperienced operator is apt to meet with an accident, usually termed an explosion, when the air temperature reaches five hundred degrees Fahrenheit, and this may occur as soon as the pressure has reached one hundred and ten pounds. The usual mode of procedure is to lubricate the cylinders in the ordinary manner with mineral oil, which is thereafter to be used in the refrigerating system. The oil used for this purpose has a low chill point, but also a low flash point. This oil is eventually discharged by the compressor into the piping, where it lodges in some pocket, and, finally, when a sufficiently high temperature reaches this pocket, is vaporized and ignited. Great pressure is the result, and the bursting of some pipe or tank in the system is the final consequence.

I have seen a tank, fifteen inches in diameter by six feet long, torn away from its pipe connections and thrown on the engine-house floor. I know of an explosion of this description taking place in the pipe system in which sufficient heat was developed to melt out all the lead joints and lead gaskets between the compressors and the condenser. I know of a man being thrown across the engine room when a pipe gave way and air of very high pressure was discharged into the room. I know of an explosion taking place in a compressor during the compression period which resulted in a broken crosshead and a broken cylinder.

It should be remembered that the final temperature of air compressed to three hundred pounds is that of red heat, and that any oil which may be used for lubrication is bound to burn at that temperature; and it is, therefore, necessary to use at least ordinary rational precaution when testing a plant, in order to prevent accidents which may result in loss of life.

I advise lubricating the inside of the compressor cylinder by

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covering the cylinder walls with a very thin coating of lard oil, using the hand to apply it; then compressing up to one hundred pounds and stopping long enough to allow the compressor to cool; then running up to one hundred and fifty pounds and again stopping to let the compressor cool. After this the compressor should be operated at a slow speed and stopped as soon as the discharge pipe becomes so hot as to make it impossible to keep one's hand on it for a period of a minute. Such procedure will positively eliminate accidents due to explosions while testing with air.

A number of operating engineers have the habit of pouring hot water over the ammonia shipping drums while charging the ammonia into the system, and some who have a steam jet handy let steam impinge against the drum, or they sometimes wrap cloth around it and stick the end of the steam hose under the cloth. If the man who does this is sufficiently intelligent to know what he is doing, it is all right, as it will accelerate the emptying of the shipping drum. If, however, as in a case I have known, the man turns off the valve on the pipe connection between the shipping drum and the charging pipe and goes to lunch, forgetting to turn off the steam, something startling will probably happen, and it did happen in the case referred to. The drum parted and was projected into a brick wall a distance of eight or ten inches. Incidentally, several hundred panes of glass in the neighborhood were broken.

The breaking of a liquid conveying pipe is an accident which has happened. It is more likely to happen with a half-inch, one-inch, or a one and a quarter-inch pipe than with any larger size. First, because these pipes are butt-welded, and, second, because they are often bent instead of being made up with elbows. Bending the pipe may crack it or open a seam. The crack may not be perceptible; the pipe is painted, and nobody sees the defect. It receives an accidental knock while filled with ammonia under pressure and breaks. To prevent this, use no long lengths of one-half-inch pipe in refrigerated rooms, and, whatever pipe is used, secure it close to the wall or to another pipe where it is least likely to be accidentally struck.

Leaks in an engine house, due to the breaking of a pipe, flange, or fitting, or due to any other cause, may be an ordinary occurrence. without any other consequence than the loss of ammonia. If, however, there are arc lights, gas lights, or any other open flame present, such leaks, if they are sufficiently large, may cause a serious accident. The mixture of ammonia, volatile impurities, oil vapor

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(that may possibly be contained therein) and hydrogen gas, resulting from disassociation of ammonia, filling the entire engine room, coming in contact with an open flame, may ignite and fill the entire engine room for a few seconds with fire, and most likely kill the people in the engine room. Such accidents can positively be prevented by having nothing but incandescent lamps in the engine room.

The breaking of compressors may be due either to leaving the stop valve in the discharge pipe shut when starting up, or to dropping a valve into the compressor. The former class of accidents, due to carelessness on the part of the operating engineer in leaving the valve on the discharge pipe shut when starting up the machine, may be guarded against by having a bypass, including a safety valve, connected from a point between the compressor and the stop valve on the discharge pipe to some point in the suction pipe. The latter class of accidents, due to the dropping of a valve, usually a suction valve, into the compressor, is, in nine cases out of ten, due to the crystallization of the material of which the valve is made. To prevent this, use valves having hollow stems wherever possible. Anneal the valves every year, and throw them away after they have been in use five years.

The breaking of governor belts may be the cause of the breaking of crossheads, steam cylinders, and even flywheels, sometimes wrecking entire plants. Every governor is, or should be, equipped with a safety stop. If this is used, the breaking of the governor belt will do no harm. The engine will simply shut down. There is a simple device, shown in Fig. 1, which does not require any special attention, but which will prevent accidents in the case of the breaking of governor belts.

The breaking of crossheads in steam engines is usually due to water in the cylinder and usually takes place when the piston is nearing the forward end of the cylinder. The cylinder head supported by the crosshead guide is stronger than the crosshead and the crosshead parts. Usually the inertia of the flywheel keeps the shaft moving, the eccentric opens the steam port, so that steam enters the cylinder at the forward end, and the piston is driven against the back head. In nine cases out of ten this breaks the head, and may also break the cylinder in line with the ports. To prevent this, superheat the steam or install an efficient steam separator close to the engine.

In a case of "freezing" of the connecting-rod brasses to the

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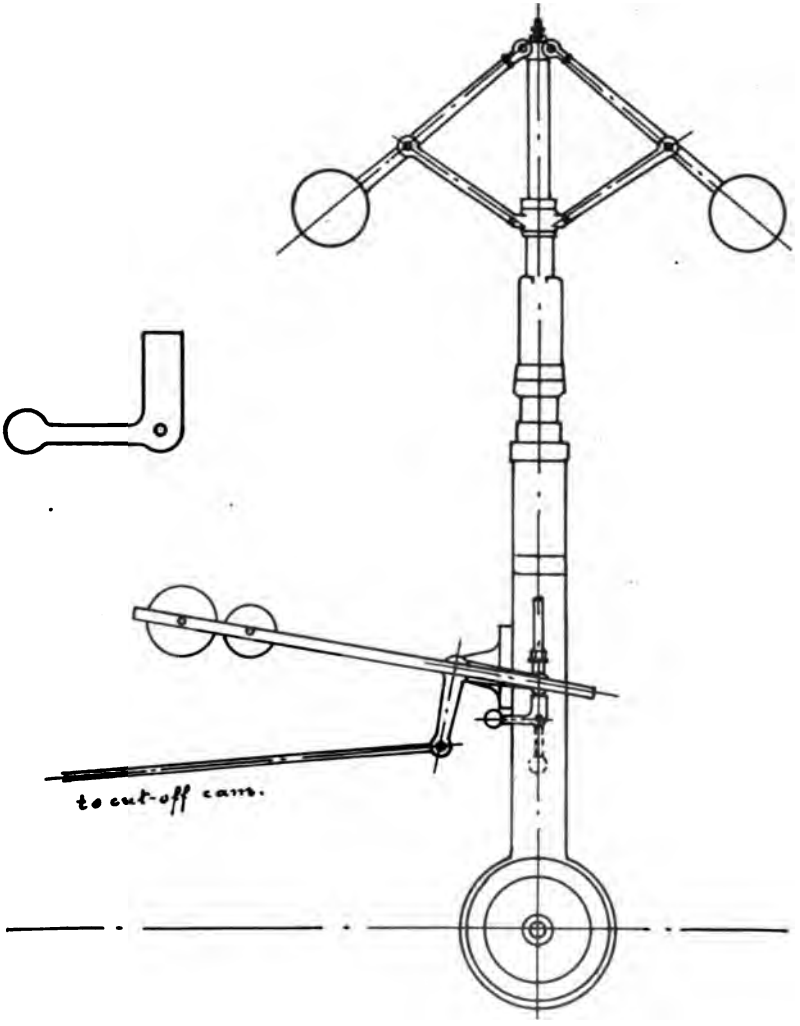

FIG. 1.—SAFETY STOP FOR CORLISS GOVERNOR.

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crankpin, which I have seen happen in a vertical machine, the connecting-rod bent to such an extent that on its down-stroke the piston hit the bottom of the cylinder. Fortunately, in this case nothing serious happened; but the flywheel might have given way, and the bottom head of the compressor cylinder might have been knocked out, and all because the crankpin was not sufficiently lubricated.

There are a number of rules which I have adopted which it may be worth while to mention. They are:

Don't use a compressor which has been used for ammonia compression, for compressing air.

Don't caulk a fitting while it is under ammonia pressure.

Don't stand in front of a gage glass when you open the gauge cocks.

Don't stand in front of a steam cylinder or compressor unless it is absolutely necessary.

All of these accidents, or at least the serious consequences, are preventable, and it should be the aim of every refrigerating engineer to do what he can towards preventing them. I have no doubt that there are many other accidents not mentioned in this paper. For the benefit of the profession it is to be hoped that the members will make many additions to the above list, calling our attention to possible dangers and pointing out means by which they may be averted.

DISCUSSION

Peter Neff.—Mr. Block's paper caused me to reminisce a little. I think most of us who have been through the practical mill of this business have bumped up against a good many of the accidents Mr. Block tells us about. I remember particularly one instance of an explosion where a plant had not, as yet, been charged, but was being tested with air. The explosion evidently took place in the connection between the compressor and the condenser. It blew the trap all to pieces, went through a 12-inch wall and blew off almost the entire end of the ammonia condenser. That explosion—I happened to be there immediately afterwards—showed no oil on the broken pieces of the trap at all; in fact, it was perfectly dry, if anything, a little carbon burnt, showing there had been a true explosion. I immediately got samples of the oil, both the oil that was in the stuffing box and being fed into the compressor, and also samples from the barrel from which it was obtained, and submitted them to a chemist. He came back with the startling announcement that under a pressure of 100 pounds with a temperature of 100 degrees that oil

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would ignite spontaneously. That shows how we are at the mercy sometimes of these oils. In regard to the rupturing of the pipes, one cannot be too careful. I remember one instance where they ran a liquid line along past a doorway—they did lay a board over it. I guess that pipe was in use five or six years, but it ultimately broke and, the stable being just beyond, killed 24 head of horses. Fortunately, it did not kill any human beings.

Louis Block.—This is perhaps a little reminiscence. The Moerlein accident used to be quoted by the Consolidated Company for the purpose of showing how dangerous ammonia was and that you should not have direct expansion.

President Shipley.—That was used only by the Consolidated people, Mr. Block?

Louis Block.—By others, too.

President Shipley.—I remember a little bit about that Moerlein accident myself. Talking about accidents of this kind, our company has had a great many such accidents, and they are caused entirely by the flashing of the oil used for lubricating the compressors. Should you use an oil that has a low flash point and compress the air to a high enough pressure, you will certainly reach that flash point, and the result will be a more or less violent explosion. Every once in a while we run up against an accident of this kind. We had quite a serious accident only a couple of years ago. An explosion occurred within a discharge pipe, connected with one of our machines which was compressing air during the testing out of the plant. The pipe was all torn to ribbons. This accident was caused by using an oil with a low flash point and subjecting it to a heat that comes from compressing air up to 150 or 200 pounds. Three hundred pounds is not an unusual pressure to be used when testing out the high side of a system, and, as you all know, the only safe way to do is to run very slow and keep your compressor very cool, that is, use lots of jacket water and keep the air going from the compressor at as low a temperature as possible. This class of accidents is very common with air compressors.

I was visiting the works of one of the ice machine builders some years ago. Just before 1 P. M. I was standing at an office window looking out at the different buildings of the plant, when all at once the engine room jumped up in the air and scattered itself over a part of the grounds. It did not take those of us who were at the window long to run to find out what was the matter. Arriving at the place where the accident occurred we found that the air compressor had

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blown up. That was another accident of the kind we have been discussing. The accident in this case occurred just after the compressor had been started up, it having been shut down during the noon hour, and evidently oil had accumulated in the discharge of the system and this oil had been heated above the flash point, causing the explosion. I suppose most of you have seen red-hot discharge pipes on air compressors. We see that very often. I saw a number of them myself before I realized what was the cause.

R. E. Bridgette.—I would like to ask the gentlemen here a question; they are talking about this oil business, for it is a very important thing. If you lead right back to those explosions you will find the oil is the agent, according to the statements just made here. What flash point would you recommend for cylinder oil for safety? If we knew what temperatures we should have we would put in the specifications we give our oil men and make them deliver us the goods.

Louis Block.—The trouble is that you cannot get such an oil; it is not in the market. If you want to get an oil with a chill point of zero or within two or three degrees of zero, you must take into the bargain an oil which has a flash point of 380 or 400 degrees; that is the best you can get, and the temperature produced by the compression of air is far above that.

R. E. Bridgette.—But what is the nearest point we can get to safety?

Louis Block.—380 degrees is the best you can get, for a purely mineral oil. As I said before, it is not wise to use any mineral oil at all for testing, or, in fact, to use anything except a little lard oil applied by the hand. That is sufficient lubrication to see you through and it is absolutely safe. In air compressors we use soap and water for lubricating purposes, because we are afraid of an explosion if oil is used.

John E. Starr.—If you will allow me to suggest, I think it has been the custom lately of most engineers to specify thermometers on the suction and discharge pipes of the compressors. Now, if a man is testing out his apparatus with air and knows the flash point of his oil, and has a thermometer on the discharge of his compressor, and will watch that thermometer and run his machine safely below the reputed flash point of the oil, the difficulty will be obviated. The ordinary engineer perhaps does not realize how rapidly the accumulation of heat from the compression of the air occurs, but if he only had a thermometer on the discharge from his compressor, and

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watched that and kept it at all times safely below the guaranteed flash point of his oil, 340 or whatever it may be, I think he would obviate the difficulty. You cannot do it by guesswork. A man cannot tell within several degrees of the temperature of a pipe by touching it. I think a thermometer on the discharge ought to be specified in a refrigerating machine in all cases, as that will lessen the danger if the engineer is only on his job.

Louis Block.—Thermometers are usually specified, I believe, but they are never specified to read up to 380 or 400 degrees. That could easily be changed, but up to the present time they have never been so specified. You want to get as large a scale as possible, and you therefore specify the highest temperature you expect to get with ammonia gas while the compressor is in operation. I want to say that I have known an explosion in an air compressor to take place 150 feet from the compressor, and whether the man knew that he had a great heat way down there in the pocket where the oil was located or not I don't know; only it seems to me that since it took place so far away from the compressor, either his discharge pipe was reasonably cool or, at least, he thought so, and still that great heat existed 150 feet away from it. I cannot explain it in any other way.

John E. Starr.—It seems to me that that should not be left to guesswork in a well-conducted plant. It would be expected that a thermometer on the discharge line would read, anyway, up to 300 degrees. I think the limit should be stretched, or even if it was only 250 degrees, let him, for safety, run his machine under an air test not above 250 degrees. That would cover almost any oil unless it be something very poor.

Louis Block.—Except what Mr. Neff stated.

John E. Starr.—I didn't hear his statement.

Peter Neff.—I took the oil right out of the barrel to a chemist and he reported back that, with a temperature of 100 degrees, 100 pounds' pressure would cause combustion of that oil.

Fred W. Wolf.—I think there are two points that have not been mentioned. In the first place, you have to figure the mixture, the percentage of oil in the air; in the second place, there are loose particles of matter in the pipe. I know one 2-stage compressor, drawing from the air and compressing to 80 pounds, the second stage pushing it out at 500. The compressor had been red-hot for two or three years to my positive knowledge, and they were feeding oil into the suction pipe to that compressor four drops a minute. Once

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we had to run a test of 105 revolutions. I used an extraordinary large amount of oil. I was looking at the gauge at the time of the explosion, and it read 275 pounds. I had my hand on the discharge pipe, and it was not over 120 or 135 degrees, as hot as you can bear your hands on.

Louis Block.—You took great chances.

Fred W. Wolf.—No, because the compressing was done in easy stages, stopping frequently to permit cooling.

President Shipley.—What caused that? You can't call that an explosion.

Fred W. Wolf.—A little piece of scale might let go or a little piece of foreign matter in the pipe might have sparked the mixture. That was compressing air on an air test. In another case a Linde machine had been converted into an air compressor, and up to the time I saw the machine in operation I believe they had fed oil in the suction line for three or four years. They don't do it now, but the plant is still running with some oil, under 500 pounds' pressure, at 125 revolutions per minute. They are using a regular ice machine cylinder oil, with a very low flash point. I have heard claims of 450 degrees for the flash point of ice machine oils, but I know that about 280 is more like it.

Louis Block.—On a cylinder oil? Oh, no, 600 degrees, as high as 600 easily. Any cylinder oil you buy, ordinary cylinder oil, has got a flash point of 500 or more.

Fred W. Wolf.—But this is not a cylinder oil; it is the Standard Oil Company's ice machine oil.

President Shipley.—Feeding it in like that, you will consume the oil, burn it up.

Fred W. Wolf.—A gas engine can be run with a mixture so rich that it will not fire with an electric spark, and with a mixture so lean that it will not fire. Except in the proper proportions it will not ignite. It is the same way with this. In addition, we have these loose particles of stuff in the pipe that very probably cause sparks.

President Shipley.—The trouble I have seen was usually where there was a pocket in the pipe, which collected a quantity of oil, and then when the heat struck this pocket of oil the damage took place. This, to my mind, accounts for some of these explosions away from the source of the heat. You must have enough oil to produce a sufficient volume of gas to give you a pressure high enough to break something or else there would just be a little flash that wouldn't

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amount to anything. That is the reason why air compressors should be started up very easily after they have been shut down, especially if oil has been used freely and has had a chance to run back and settle in pockets. Even little films of oil through the piping may gravitate back to a pocket when the compressor is shut down, thus affording sufficient body to cause trouble if the proper heat is brought in contact with it.

Louis Block.—I don't think that what Mr. Wolf has stated is entirely applicable to the subject which we are discussing. He says—and I don't want that impression to go forth—that a lean mixture cannot be ignited. He is thinking of an electric spark. Of course, an electric spark will not ignite a lean mixture, but a temperature of 800 degrees will ignite it, and you can easily get it by compressing up to 300 pounds.

Fred W. Wolf.—The temperature in the discharge pipe was less than 140 degrees.

Louis Block.—You cannot have 140 degrees in your discharge pipe.

Fred W. Wolf.—I run it up to 100 and then give it a chance to cool down, then run it up to 150 and cool it again.

Louis Block.—Oh, that's a different proposition. That will do it every time.

President Shipley.—Mr. Block's paper calls attention to several "don'ts." There is one "don't," the second one, "Don't caulk a fitting while it is under ammonia pressure," that may seem a little bit simple, but I want to tell you that is one of the things we have to avoid, at least it is one of the things that we should avoid. The erecting engineer, or a man about an ammonia plant, will see a little leak and think he is working for the interests of all concerned when he attempts to doctor that leak by caulking, and instead of taking out the defective piece or putting the fitting on right. If he only stops to think he will realize that work of this kind is very dangerous, to say the least, and such practice should be avoided if possible, especially on light parts. When a man goes to work and caulks a fitting or tries to caulk a leak he is playing with something that is liable to get him and everybody around the place into serious trouble. That is one thing I talk about a good deal to our men. I tell them how much cheaper it is for us to furnish new fittings than new men or new plants, and while we might save a fraction of a dollar or a part of a ten-dollar bill by their zeal in this caulking game, in the long run we lose thousands of dollars, and it is the long run that

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counts. It is the average we care about; it is not the individual case. It is much cheaper to take the fitting off and throw it away or find out what is the matter and make it right than it is to try to doctor it.

Peter Neff.—In Mr. Block's paper, in regard to the sort of explosions that take place when you have the discharge valve shut and rupture your cylinder, a gentleman told me recently that at one time he was standing by when they were starting up a machine and explosion took place that blew the head off the compressor. They had started with the discharge valve shut, and he said he could see the gas rush out for quite a while before it fired, and then it fired and burnt the roof off his building. In another case I know of, under the same conditions, starting up with the discharge valve shut, the head was ruptured, the flame seemed to come instantly and was sufficient to burn a man thirty feet away. I would like to hear a little explanation as to what causes the explosion with ammonia under those conditions.

President Shipley.—Accidents of that kind, I am led to believe, are caused by the mixture of air and ammonia and the vapor of oil coming in contact with a flame, as Mr. Block's paper suggests. Arc lights are productive of such explosions. Now, it is possible that some of you have in mind an explosion that took place up in Ruppert's brewery here not long ago. There was a breakage in four one-inch valves; the bottom of the valves blew out; the bottom of the four valves were right in line. Something happened in that system, either the shutting off of the condensers or something of that kind, which threw a sufficient pressure on those valves to burst the bottom out of them. This liberated the ammonia, and the engine room filled up with the ammonia and oil vapors, which, coming in contact with the arc lights, caused two distinct explosions. Nothing else was hurt about the ice-making apparatus but the bottom of those valves, but the explosion which took place tore out the windows and jarred the neighborhood. The worst of it was that there were four men killed in that explosion, which was greatly to be deplored. There is no doubt in my mind but that the explosion was caused by the oil and ammonia, mixed with the air, coming in contact with the flame of the arc lights.

H. Dannenbaum.—This case was referred by the Board of Fire Underwriters to the Bureau of Mines in Washington, and they offered two explanations. One was that the mixture of vaporized oil and air could have caused the explosion. The other was that the ammonia was decomposed by the heat of the arc lights, and

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formed an explosive mixture with the air. The explanation would be that free hydrogen was formed and the hydrogen, mixing with the oxygen of the air, formed an explosive mixture. This explanation was referred to the chemist of the Bureau of Explosives maintained by the railroads here for their opinion, and he did not consider it likely that, in the short space of time, if I remember the report rightly, the time that elapsed between the breaking of the valves and the explosion was given as three to four minutes, there could hardly be sufficient hydrogen formed to cause an explosion. I am of the same opinion and do not believe sufficient ammonia could be decomposed in that time to form enough hydrogen for an explosive mixture. I believe it was the mixture of oil and air that exploded, and that the ammonia had nothing to do with it at all. These explosions are carefully investigated by various boards of underwriters. The Board of Underwriters in Philadelphia took the matter up with Mr. Bower and asked for an explanation of this explosion. If they should happen more frequently I believe there would be trouble with insurance. Mr. Block recommended that there should be no arc lights in the engine room, and I believe that is very desirable. I don't think there ought to be any open lights in an engine room; incandescent lamps ought to be used, and explosions of oil and air or of products of decomposition of ammonia, if there is something in that, could positively not happen.

William H. Bower.—Speaking of the matter from a chemical standpoint, I might say something that would support the view that it is impossible for ammonia to decompose in an open light, even in the case of arc lights. I was told to-day of a rupture of a hose which was carrying anhydrous ammonia from the storage tank where the anhydrous ammonia was stored, into cylinders, and the ammonia flooded the room immediately. The valve was in such a position that they could not get at it to shut off the ammonia. There were eight coal oil lamps, all of them above the ammonia, one directly above the cylinder, so that they could note the weights on the scales as the cylinder was filled. The men were driven out of the filling room and they looked through the doors and windows and saw the lights, one by one, extinguished all around the room. My opinion is, from what I know of the decomposition of ammonia, that it is absolutely impossible for enough hydrogen to accumulate around any exposed lights to cause an explosion.

President Shipley.—Right along that line I might say that I had an experience, about twenty years ago, where a two-inch liquid line

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broke while we were erecting a plant into which we had put 150 drums of ammonia. The trouble occurred at night. They sent for me, and when I arrived at the plant I found the liquid running around the floor in streams. The engine room was next to the fire room, with open spaces between the columns, so that the ammonia had free access to the fire room. The fumes of the ammonia had driven the firemen away from their fires. Before leaving the firemen had opened the fire doors of the boilers, so that the steam could not go up, thus giving the ammonia a chance to get right on the red-hot coals. I went in with a gang of men and fought that stream of liquid ammonia until we finally got a valve shut. There were several carbon arc lights in both boiler and engine room, but no explosion or trouble of that kind occurred. It was on a system where oil was not used, except for lubrication of the engine, hence there was no oil to mix up with the ammonia, and we had no explosion. The only place I have ever seen explosions was where they used oil in abundance. The only systems I ever knew of that had this trouble were of that kind, so, to my mind, there is no question but that it is the mixture of oil and ammonia that causes the explosion. I have had gangs of men hunting ammonia leaks with candles times without number without the slightest accident. The machines I have been about, however, were those which did not use oil in abundance in the compressors. I have been where you could cut the ammonia with a knife with naked lights and had no explosion.

John E. Starr.—I suppose we are after the truth in this thing, but if you remember in that case of——

President Shipley.—Is this a reminiscence or a dream?

John E. Starr.—This is a reminiscence. In the case of the York Manufacturing Company, in which I happened to be on the opposite side of the case against our president. In that case we were prepared to show that under certain circumstances ammonia, whether it was mixed with oil or not, providing the right admixture of air and ammonia was used, would produce a flame that would shoot up and communicate fire to other ordinarily combustible substances. In the judgment of the Honorable Court in York we were not permitted to show that experiment in court, but I can assure you that we had eight samples of ammonia there. There were six samples from the principal manufacturers; one sample that was made by a purely absorption process, that is to say, by a process in which the ammonia was distilled out of the aqua ammonia and purified by low temperature, which chilled the water out of it

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under high pressure, conditions which should ensure perfectly pure ammonia, and there was another sample taken directly from an absorption machine. In all of the eight experiments made with these samples, after learning the proper manipulation, we had little difficulty in getting a flame. We had a small cylinder of each sample, containing about five pounds of ammonia; on the floor we placed a pan; we fitted each cylinder with an expansion valve, whereby we could shower a stream of ammonia down towards the pan. One man held a piece of newspaper in his hand about four feet above this pan, just a little above the cylinder; another man held a taper in his hand at the floor. With a little practice I was able to turn the valve so as to shower the ammonia down just right, a white mixture coming out of the valve, becoming almost colorless as it reached the taper, and in every case, with every sample of ammonia, we produced a flame, lighted from this taper, that would rise up about four feet and light the newspaper above the cylinder, that is, about four feet from the taper on the floor. There were eight samples of ammonia and there was absolutely no difference in the phenomena in any case.

I may say, however, that in every case, by opening the valve wider and showering the ammonia down more strongly, we could put out the taper below and no flame would follow, but in every case where the manipulation was right—it took some time to get it just right—in every case where it was right, we could produce a mixture of ammonia that would ignite on the floor and produce a great flame that would rise up sufficiently to light a newspaper held four feet above it. It may be said that in every case where the ammonia was obtained from the regular manufacturers there might have been some oil in it. It may further be said that in the other two cases there might have been some other inflammable gases in the ammonia, that is, in the case where it came from the absorption machine and in the case where it came from a plant that was manufacturing ammonia simply by the dehydrated process, but there was absolutely no difference in the phenomena when the eight cases were handled the same way.

President Shipley.—You had a pan of water down on the floor?

John E. Starr.—No, just a dishpan.

President Shipley.—Now, to tell you the other side of this particular case Mr. Starr refers to: On our side we were prepared to take tar barrels, fire them up, get them blazing and put the fire out with ammonia.

John E. Starr.—Quite true.

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President Shipley.—That's the kind of a game you get when you have explosions; you don't have these little mixtures that you have to work with a long time to get a knack of. When the cylinder head breaks, the ammonia comes out on a dead run and there's no fooling with it, because it chases you off the perch. There's none of us who have had experience with ammonia but have had our whiskers singed and our eyebrows burnt by the flashing of ammonia. When we catch it in a pocket, around the stuffing boxes, where a man goes looking for a leak with a candle, as we often do or often did when I was going around on that kind of work. I have had my face singed I don't know how many times by a blue flash, and after that the skin of the housing would be found as dry as a bone. The oil was all burnt off; it was the oil that flashed, not the ammonia, although, in hunting for a leak, once in a while we would get a little blue flame, but we wouldn't have any flash unless we were where there was oil.. This is a common occurrence around these machines. Our men are doing that kind of work every day, and they would all be blown to Kingdom Come if pure ammonia would explode when it comes in contact with a light. I have had to do with a great number of plants and a greater number of men, and the only trouble any of these men have ever had in connection with ammonia was where they have bumped up against a plant that was loaded with oil, and I don't believe you can bring up a single case where there was an explosion caused by the leakage of ammonia, unless the system was heavily charged with oil.

John E. Starr.—I think I can bring up a case that happened in St. Louis. I am not arguing at all on the danger of ammonia, because I think it is very remote, but I am arguing that there are certain admixtures of ammonia and air that will ignite. It may be due to the presence of oil or other inflammable gases, even in an absorption machine, but, as you have asked for an instance, I can give you one. In St. Louis, many years ago, an ammonia pipe broke in a certain basement. There was a gas jet burning in the basement some distance away from where the break occurred. The first immediate result of the break of that pipe was a flame which charred the whole interior of the room, which was about the size of this one. Immediately following, the ammonia came in such large volumes that it put out the fire and saved the building by excluding all the oxygen. There was a case where the explosion was very beneficial, as long as there was going to be a fire, anyway, but the first thing that hap-

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pened, when the admixture came just right, was to cause a flame which charred every piece of wood in that room.

President Shipley.—But did you have an explosion?

John E. Starr.—Yes, a flame burst up through the trap door leading into the engine room. That was a case that I saw myself. I was standing there and had a hard time keeping the fire department out of it, because they were confused by the fumes of ammonia and insisted on pouring water down into that place when I knew the fire was all out.

President Shipley.—The windows were all blown out?

John E. Starr.—No, a sheet of flame simply burst up through a trap door. I saw the flame myself. I was standing in the room, and it charred every piece of wood in the room below, but immediately afterwards the rush of the thick ammonia came in and put the fire out just as neatly as you could put it out with carbonic acid gas or by pouring water on it. It saved the building. That was in the old fountain absorber days, so far back that I'm afraid to say when it was.

Henry Vogt.—I would like to ask Mr. Starr if he has had experience in any case where ammonia from an absorption machine has blown up and set fire to a building?

President Shipley.—It is an absorption machine that we are speaking of?

John E. Starr.—No, that was the only case that I knew of where that happened.

Henry Vogt.—It put the fire out.

John E. Starr.—First made a fire and then put the fire out.

President Shipley.—Mr. Vogt would like to keep such troubles with absorption plants off our records, but Mr. Starr has cited an absorption machine case; in fact, he has no other case he can cite.

H. Dannenbaum.—I don't believe in the case which Mr. Starr mentioned there was any explosion; it was simply decomposition of ammonia, by which some hydrogen was formed, and the oxygen of the air being there, it burnt; more ammonia came and excluded the air and the fire went out. If you open the valve of an ammonia cylinder very slightly, so very little ammonia gas will come out, and you hold it to an ordinary candle, you will produce a wavering, floating flame. As soon as you take the candle away, the flame goes out, because the heat of decomposition is not sufficient to make it self-supporting. In the case mentioned by Mr. Starr some hydrogen was formed and it burnt a little while; then more ammonia came

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and excluded the air and put the fire out. When I speak of an explosion I mean cases like that at Ruppert's brewery, where the windows were blown out and where an actual explosion occurred.

John E. Starr.—I am quite in accord with Mr. Dannenbaum. When I said an explosion I meant it was an explosion not such as would wreck a building or anything of that kind, but a sudden burst of flames in a small aperture. I did not mean that it was a wrecking explosion, and I think that Mr. Dannenbaum's explanation of it is exactly what occurred in the case I cite.

President Shipley.—That's the reason we wouldn't stand for your laboratory experiments with flash lights in York. We were on to that game ourselves, and you couldn't work that on a York Judge. I want to tell you another thing about this case. Mr. Starr's crowd took one of our witnesses up in their laboratory to show him this phenomenon, and the next day in the court, when he wanted to pull his flash trick on us, this fellow jumped up in the audience and yelled: "Judge, the ammonia was rotten." That settled it, and we put it all over those fellows.

Charles H. Herter.—In Cleveland, O., a 250-ton vertical machine was started up about five o'clock in the morning and, after running about three-quarters of a minute, the head blew up and broke the incandescent bulbs and set the establishment afire, and there was no open flame around, nothing except the incandescent bulbs; nevertheless, there was a fire started that lasted all day.

Peter Neff.—That was the way with the one I referred to when I spoke of burning a man thirty feet away.

Fred W. Wolf.—From a new absorption machine, one having no moving parts and no oil, there was a leak from the liquid line, and, just for the fun of the thing, I let it drop on to a match. The result was that right up to the ceiling we had a violent explosion. To see if the thing would be different the next time I lit another match and we had a flame. Then we got about three or four more explosions, each less in intensity, but the first one was a violent explosion, and there was nothing but ammonia and a match. The second, due, probably, to less oxygen in the air, was less violent. The third and fourth were pure flame, and after that I couldn't get any flame, probably due to too little oxygen left in the air. The room did not have very good ventilation, this was in a corner and there was very little or no circulation of air, and the odor was very strong by the time we got through.

President Shipley.—Mr. Vogt, is that not a case of burning off the foul gases usually spoken of?

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Henry Vogt.—I believe that it proves that an ammonia absorption machine will put out a fire.

Fred W. Wolf.—I call your attention to the fact that this was a new machine, and there was liquid ammonia and no foul gas; there couldn't have been; it had just been charged; the ammonia had never been heated.

Harry M. Edwards.—What part of the apparatus blew up?

President Shipley.—The part of the machine that broke was the top head. It was a solid head machine, with a suction and a discharge valve in it, like the Consolidated people used to build. The discharge valve went through the seat, and then, when the piston came up, ruptured the solid head and liberated the ammonia in the room and there was a fire, which burned down the Schenley Park Casino. Just what caused this fire was never explained satisfactorily.

Harry M. Edwards.—Wasn't there an explosion of drums stored somewhere in that building in Schenley Park?

President Shipley.—Not until after the fire got hot did they burst.

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No. 103

AMMONIA COMPRESSOR SAFETY DEVICES

By Peter Neff, Canton, Ohio

(Member of the Society)

Safety devices for compressors may be divided into two classes:

First—Those which provide protection against accidents resulting from breakage of parts which go to make up the entire compressor.

Second—Those which provide against damage resulting from other than inherent causes.

The first class provides against such accidents as the breaking of valves, rupturing of cylinder walls and heads, breakage of piston rods and rings, and the like.

The breaking of the valves in the early days of refrigerating practice was probably the greatest source of damage to compressors with which the manufacturer had to contend. This defect has to a large extent been eliminated:

A—By the ability of the manufacturer to secure for the construction of his valves a grade of material which does not so readily tend to crystallize.

B—By constructing the valves so that they are more or less cushioned in their operation, thereby avoiding the shock which is the greatest factor in producing crystallization.

C—By locating the valves in such a way that the broken parts remain in the pocket in which the valve operates and cannot enter the cylinder. This method of avoiding the trouble was condemned for many years, because of the idea that the effect of clearance in the compressor is detrimental to its efficiency, which, however, does not occasion a loss in true efficiency. If the manufacturer constructs his compressor of the proper size to allow for the volumetric loss occasioned by these pockets, he is still in position to argue on the question of the true efficiency, which is the ratio of the horse power required to operate the compressor to the ton of refrigeration. Had this been more distinctly understood and properly elucidated, especially in the early days of the art, we believe it would have done much

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to facilitate the overcoming of this trouble, for had the manufacturer realized that he could have arranged his valves in pockets with perfect safety, and by increasing the size of his compressor could have accomplished the same work as before, with the same expenditure of energy, he would have been able to go before the public with only a little more weight and size to handicap him.

D—By designing the valve so as to eliminate its tendency to crystallize and wear.

E—By the use of a false head in the compressor, covering the entire bore, which is held in place by springs of greater tension than the pressure ordinarily exerted on the head. This method is not applicable except in vertical single-acting compressors.

The devices and conditions referred to have been brought into use in different combinations by various manufacturers, with the general result that, as now constructed, compressors are more free from inherent defects than ever before. There is, however, room for improvement, and it would seem that this improvement is to be looked for along the lines of better materials from which to construct the valves; better design by which to avoid unnecessary wear and tendency to crystallization, and more careful locating of these valves.

As to the structural strength of compressors and compressor heads, this has not been a source of much concern, as the manufacturer soon learned that certain grades of material were necessary for the construction of these parts. In many instances, however, compressors are weakened through faulty design where shrinkage strains are not taken into account. Such strains are not always apparent, but may appear as time goes on.

Piston rods and heads have given little trouble, as it has been easy to figure the strains to which they are subjected and to allow liberally for them. As to piston rings, very many types have been tried, some of which have produced accidents; but of late years the ordinary snap ring seems to have best met the conditions of service, and very little trouble should be experienced from such rings if properly made and adjusted.

The first class of safety devices embraces nothing but what the manufacturer should be able to control by careful calculations, and the results of experience. This also applies generally to what is to be said with regard to the second class. In other words, in the construction of some safety devices the manufacturer must have in mind liability to accident from causes arising under both classes.

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The second class deals with such accidents as are caused by explosions, unusual pressures, the presence of liquid in the compressor, and the like:

A—As to explosions, the manufacturer cannot protect his product against this contingency by any mechanical device. They usually result from a mixture of compressed air and oil vapors. Other causes have been suggested, but a discussion of this phenomenon is scarcely permissible in this paper. The best guard against such accidents is judgment and care on the part of the operator, but even this does not eliminate a certain percentage of chance, due to the working of unknown laws.

B—For unusual pressures there is first the general construction, which should have a sufficient factor of safety to provide for ordinary increases of pressure which are likely to occur. When a machine is started with the discharge valve shut, for example, the power applied is usually sufficient to cause a pressure far beyond that which prudence would dictate should be considered in compressor construction. Failure may not take place in the compressor, but in some weaker part of the machine. To avoid this, one method is to make a connection between the discharge side pipe of the compressor at a point before it reaches the stop valve, and the suction side of the machine beyond the suction stop valve. In this connection is inserted a relief valve similar to a safety valve. The difficulty with this device is the same as with any steam safety valve. If not used it tends to become useless, and when used too frequently is apt to leak. The first destroys its purpose and the latter causes constant loss in operation. This method, notwithstanding its faults, seems to be the best available at the present time, and should be improved along the lines of better seating and a better arrangement for operating by hand, so that it can be tested daily. Another method has been to make a relief valve of the discharge stop valve. This will take care of excessive pressure in the compressor itself, but is of no value when the excessive pressure is in the condenser, which may occur under certain conditions, and the method is therefore at best of only limited value.

For protecting against the presence of liquid in the compressor —and here we have a very real and ever present danger, no matter how carefully the system may be designed—the false head applicable to vertical single-acting compressors would seem to be all that is necessary, but such a device gives rise to disadvantageous conditions which have to be balanced against the advantages of safety. First,

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when the false head opens, it may or may not close tight again. Second, the construction detracts to a large extent from the usefulness of the cooling water, owing to the gaseous space between the false head and the head proper. In small compressors where the discharge valve is of the same diameter as the compressor, satisfactory and safe results are accomplished.

To avoid this difficulty in vertical and horizontal double-acting types of compressors the location of the discharge valve must be such as to cause the liquid present to be practically all discharged before the piston reaches the end of the stroke; not an insurmountable condition to be attained.

There is abundant opportunity for improvement in safety devices for compressors, and engineers should not be content to let well enough alone. We should not be beguiled into believing there is no danger in the operation of compressors. Accidents resulting in loss of life do occur, and life, no matter how infrequently such accidents occur, is a fearful price to pay for the neglect of possible safety devices.

DISCUSSION.

President Shipley.—Mr. Neff makes the statement that false head compressors cannot be used horizontally. I believe that statement is erroneous. I can show him false head compressors that have been running for ten years continuously. There is no question but that it is possible to run false head compressors horizontally, if you want to. I mention this in order that Mr. Neff's statement may not go on the records unchallenged.

Peter Neff.—Some one asked regarding what I said about trap pressure control in the beginning of my paper. When I reached here this morning I got a letter from my old friend, Criswell, who says, "If you are going to read that paper, don't forget to say something about this trap pressure control." It was the first time the matter had been called to my attention, and so I took occasion to mention the fact. It seems to me, from what little study I have given it, that it depends on a pressure underneath a connection to the engine governor, so that if your pressure increases, the governor is lifted and the safety trip thrown in; that seems to be the idea. In that little pamphlet he mentions some of the users, and I think he refers to your company as having used one of them.

President Shipley.—Yes, it is a governor controlling device, operating the same as any kind of a pressure control that you might

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put on your throttle valve. If the pressure increases beyond a certain number of pounds it exerts a pressure on a piston which so operates as to shut off the steam from the engine, either through the governor or directly on the throttle valve, shutting off the steam and closing down the machine.

Charles H. Herter.—In this list of safety devices there was one not mentioned that I consider to be a good scheme, namely, the cast-iron breaking plates used by the De La Vergne Machine Company and by German builders of CO_2 compressors. I think it is a very simple device and one that could be used in all places.

President Shipley.—Yes, the De La Vergne people used to have a sort of a false head held down by a breaking plate that would let go in case of undue pressure, and relieve the pressure within the barrel of the compressor. The Frick Company also had a similar device for holding down their false heads. I got that up myself when we couldn't make the springs work. I made a cast-iron lock, consisting of a little piece of cast iron with an offset on it and nicked it on top so that I could clamp the valve down; if anything came underneath that was strong enough to break the lugs, it would allow the false head to raise. After we got so that we knew how to make springs we discarded that sort of proposition, but breaking plates have been used in a number of different ways for that purpose.

I suppose you are all thoroughly familiar with the fact that most of the locomotive cylinder heads are scored so that in case there's any difficulty it will just take out the centre of the head, and not tear the flanges off the cylinder. That has been tried on steam engines for power plant purposes, but it soon brought the builder into bad repute, for the reason that it looked as if he expected his cylinders to let go somewhere. Such an engine requires a notice to be sure to obey this last "don't" of Mr. Block's: "Don't stand in front of steam cylinders or compressors unless absolutely necessary." We wouldn't want to stand in front of a cylinder the head of which was scored so it could break easily. You might as well stand in front of a gun.

John L. Plock.—When I was designing engineer for the De La Vergne Company I found that apparently little was known about the maximum shearing strength of circular cast-iron plates supported by a ring. As a consequence, the thickness of the castings comprising these so-called "breaking plates" was largely a matter of guesswork on the part of the draughtsmen, and if a valve dropped

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in the cylinder this breaking plate very often did not work. As a consequence, the head of the compressor was likely to be blown off. This lack of available data for the proper design of breaking plates was noticed by me at the time we designed a machine similar to the compressor now being built by the Arctic Ice Machine Company, in which we proposed to make a collapsible piston by means of breaking plates. At that time I looked all through the text books for a suitable formula, but was unable to find any, and we resorted to a series of experiments, from which data we made up a formula and figured the various constants. These breaking plates were a series of small cylinders bored and turned to exactly the same dimensions and having at one end of the cylinder a thin plate of cast iron from 1-16 inch to ½ inch thickness. This thin plate had a hole in it for centering a hardened steel plunger, which had an outside diameter equal to the bore of the cylinder making up the breaking plate. Putting this breaking plate and plunger in a testing machine we sheared out these plates and made proper records.

It might be interesting to relate quite a serious accident which occurred while making these tests. It had not occurred to us to box in the breaking plate, and while operating the testing machine one of these rings exploded and one of the men was quite seriously injured. We could only account for the explosion as being due to the initial stresses in the casting due to the cooling of the iron, being released when the plate at the end of the cylinder making up the body of the breaking plate was sheared out, resulting in shattering of the cylindrical body of the breaking plate. My experience led me to the conclusion that the breaking plate was a very good thing if designed by some one who knew how to do it, but if they were going to be designed "hit or miss" or "by rule of thumb," that you could not expect any results other than a possible blown out cylinder head in case a valve dropped into the ammonia compressor.

I think it is a very good plan to make the crosshead the weakest part of the machine. If a valve should then drop into the cylinder the added strain would be on the weak crosshead, causing it to crack. I have seen an accident caused by one of the compressor valves dropping in the cylinder in one of the breweries in New York City some years ago, where the crosshead was the weakest member of the machine. The valve was flattened out, and, with the exception of the crosshead, which was partly crushed, and a slight bend in the connecting rod, nothing else happened. I think you will agree

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that in the absence of the information necessary to properly design a breaking plate it is much better to rely upon a weak crosshead.

John E. Starr.—I don't want to weary you, but there is one more incident very fresh in my mind. I have just come back from Florida and found four plants there where they were in the habit of leaving the ammonia cylinder connected to the liquid line, on the theory that when they wanted to put in a little more liquid they could simply open the valve and let the ammonia into the liquid line. I found those four cases in Florida, and I have had three other cases of that kind, law cases, where an explosion had followed from just exactly that thing, where the ammonia cylinder was connected with the liquid line, where the valves were leaking, and where the pressure on the condenser was superior to the pressure corresponding to the temperature surrounding the cylinder. Under these conditions, instead of the ammonia cylinder discharging into the liquid line, the liquid flowed into the ammonia cylinder and filled it entirely full, so there was no gas space left. In three cases I could mention, the engineer, thinking the cylinder was empty instead of full, disconnected it and shut the valve on the cylinder, which, with a sufficient rise in temperature, of course, exploded. In one case two men were killed; in another case one man was killed, and in another case a man was very badly injured. I had to defend those cases. I found four cases in Florida in the last week where the same thing might occur. I think that is a very reprehensible practice.

President Shipley.—I think that is one of the don'ts we ought to put in red letters. I think that Mr. Dannenbaum ought to tell us something about the danger in filling drums too full, so as to impress it on our minds. If he will tell us what precaution they have to take in ammonia works so as not to fill shipping drums too full of liquid he will do us much good.

H. Dannenbaum.—We put only 105 pounds of ammonia in standard size cylinders, 10 inches in diameter and 7 feet long, which hold 122 pounds at ordinary temperature. This allows the cylinder to be heated to approximately 165 degrees Fahr. before it will be completely filled with the liquid ammonia. If the temperature goes very much above 165 or 170 degrees, hydraulic pressure sets in and the cylinder has to go. We come across many cases where cylinders are over-filled by people who withdraw charges from their machines. Every winter we have cases where over-filled cylinders come back, sometimes containing 120 pounds of ammonia, and it is, of course,

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only fortunate that such a cylinder does not get into a warm room or it would explode. A case of an explosion similar to the one Mr. Starr mentioned happened in a cold storage plant a year ago this summer. The manager of the plant wrote us that his night engineer had emptied a cylinder of ammonia into his system, had closed the valves, and two hours afterwards the cylinder blew up. An investigation developed the fact that they carried the full ammonia cylinders in a cold storage room at a very low temperature, and when he connected a cylinder to his system the ammonia, instead of going from the cylinder into the system, went the other way and completely filled the cylinder. The engineer closed the valve and the cylinder exploded as soon as it got warmed up. The manager wrote us that he carried the cylinders in the cold storage room because he thought it was the best place for them. It is not necessary to keep cylinders in a cold storage room. As long as you keep them dry and the temperature is not excessive, it is better if you don't put them there.

Over-filling of cylinders is very dangerous. I remember a case where a man got a very small cylinder filled with anhydrous ammonia by a dealer in chemicals who supplies small amounts of anhydrous ammonia for experimental purposes. If we do not know the exact capacity of such small cylinders we take out the valves and determine it by filling them with water. We then dry the cylinders and fill them with ½ pound anhydrous ammonia for every pound of water. The dealer did not take this precaution, but over-filled it, and the only thing that saved it was that the flat head of the cylinder bulged a little bit, causing it to leak at the valve threads, so that some ammonia could escape, or the cylinder would have exploded while it was being handled by the express company. I would ask you to instruct all your erecting engineers that they must be very careful in drawing out ammonia and that they should always *weigh* the cylinders before they ship them, and not take it for granted that the cylinder is not entirely full. If there is no air in the cylinder, the ammonia will go in very rapidly and may fill it entirely, and unless you weigh it you don't know how much you have in it.

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No. 104

THE MANUFACTURE OF DISTILLED WATER CAN ICE

By N. H. Hiller, Carbondale, Pa.
(*Member of the Society*)

The question that comes to the mind of every prospective purchaser of an ice making plant is, "How much does it cost to make ice?" and, unfortunately, up to the present time there is no definite basis by which this ice-making cost can be determined. Various estimates of cost, ranging from 35 cents to $2.00 per ton, have been made, depending upon the operating conditions, size of plant, etc. A survey of some of the older catalogues of ice-making machinery shows a variation almost as great as the above-quoted cost. One of these catalogues gives the detailed cost of ice making as to labor, fuel and supplies on various sized plants, from 1 ton to 100 tons capacity, while present-day catalogues avoid the subject entirely. A careful averaging of the costs given in a table in this catalogue shows the fuel item to be 58 per cent., the labor 35 per cent. and supplies 7 per cent. of the total cost.

An efficiency diagram of ice making costs and all the dependent items is shown in Fig. 1. It will be seen that this cost is divided into two main groups—namely, operating expense and overhead expense. The operating expense is dependent largely on the design and construction of the plant. Consequently, as engineers, we are more vitally interested in the first group and all the various subheadings that go to make up the operating expense. Fuel cost, being much the largest item, presents itself as the one offering the best chance of reduction, and is the one this paper covers. It should be borne in mind that the cutting down of the fuel consumption means, on a large plant, a corresponding saving in labor, due to the decrease in the quantity of coal and ashes handled. The primary causes that affect the fuel item, as shown in the diagram, depend upon the efficiency of the boiler plant, refrigerating machine and *distilling* system. The boiler plant, in turn, is governed by quality of the coal, type of setting and firing. Of these last items, quality of fuel is the greatest variable, and the one regarding which most operating engineers have the least data. At the plant of the Muncie Ice & Coal

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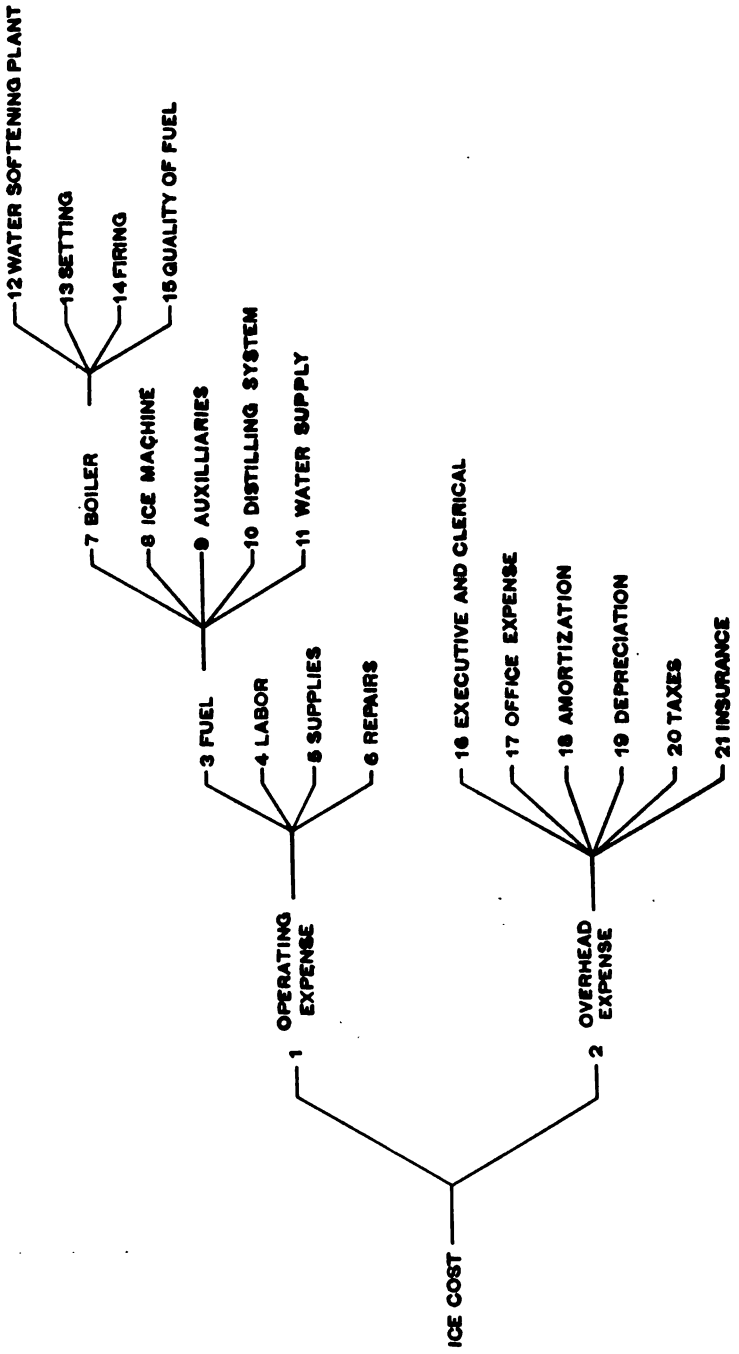

FIG. 1

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Co., Muncie, Ind., various kinds of coal were tried out during the past summer and a careful record kept, covering the amount of coal burned and the ice produced. This plant is equipped with a Carbondale exhaust steam evaporator ice making system. Analyses of these coals were made, and received from the chemists some weeks after the completion of the tests. The following Table I gives the results of these analyses and the economy of the plant with each coal:

TABLE I.—COAL ANALYSES.

	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.	Sample No. 5.	Sample No. 6.
Moisture	7.76	10.64	3.38	.99	1.30	.82
Volat. Comb. Matter	35.18	32.57	34.78	38.69	35.64	35.18
Fixed Carbon	50.57	48.21	55.64	55.12	57.11	60.68
Ash	6.49	8.58	6.20	5.20	5.95	3.32
Sulphur	1.51	.89	1.32	1.12	.87	.62
B. T. U	12377	11892	13349	14283	14203	14854
Economy	8.9 to 1	7.6 to 1	9.4 to 1	10.3 to 1	10.8 to 1	11.25 to 1

From these analyses I have reduced the various coals to a combustion basis; the economy of the plant has also been brought to a similar basis, and the two lines in Fig. 2 plotted. It will be noticed that while the B. t. u. curve is practically a straight line, the economy curve is a broken one. There is one point, point 2, which is very much out of line. This is due to a condition which existed at the plant at the time this test was run—i.e., dirty feed-water heater coils. These were afterward cleaned, and much better results obtained. Unfortunately, no sample of the coal was taken at the time the second test was made, although the coal for both tests was obtained from the same mine. It is, therefore, impossible to plot point 2 on the diagram with any degree of accuracy. Disregarding this point and drawing a line parallel to the B. t. u. line, starting at point 1, gives a line that runs very close to the various other points, and, I believe, as close as it is possible to expect a practical test, that continues through several weeks, to check. It was impossible at the time these various tests were made to determine the actual evaporation, because this plant is used in conjunction with the Carbondale evaporator system. A portion of the feed-water was sent to the boiler, the rest being diverted to the evaporator; but there was no way to determine the relative quantities fed to the boiler and evaporator.

The above results, although very interesting, fail to establish the real efficiency of the plant, based on boiler evaporation. It was,

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therefore, decided to investigate this point further and arrange the plant for a more elaborate test. The writer does not recall any data on an absorption plant where the individual items of steam consumption have been determined, so that the total steam furnished by the boiler would balance with the ice made, etc. In order to determine the actual efficiency of this evaporator system, it was decided to install Venturi water meters and General Electric steam meters to check up these items.

Referring to Fig. 3, a General Electric steam flow meter was attached at point *A* and also at *D*—the one at *A* to give the total amount of steam that the boiler evaporated and the one at *D* the amount of steam that the evaporator made. A Venturi meter was placed on the evaporator condensation at *E* and another connection was made to the generator condensation *G*.

By the time the plant was arranged for the test the conditions were not so favorable as they had been earlier in the season. The water supply, which had been gradually decreasing throughout the summer, had dropped to a very low ebb, so that it was necessary to run the air compressors at a speed more than double that used during the first test. Early in the season it was necessary to operate but one air compressor in order to get an ample supply of water, while during the time of this test both compressors were run at full speed, and even then only a limited supply of water was obtained. This water was of good quality, 56 degrees in temperature, and the consumption was 160 gallons per minute for a capacity of 60 tons of ice daily. Unfortunately, the high speed of the air compressors gave more exhaust steam than the generator of the ice machine required, and, in order to determine this amount, the surplus exhaust was condensed and weighed at *H*. All of the various quantities shown in Fig. 3 are in pounds of steam per hour and on a basis of 60 tons of ice per day. To explain the diagram a little more fully, it may be well to say that the boiler furnished 3,890 pounds of live steam per hour under a pressure of 120 pounds. This steam was divided into two streams, the larger one, *C*, amounting to 2,400 pounds, going to the evaporator, and the smaller quantity, *B*, of 1,490 pounds, passing through a by-pass valve, as make-up steam necessary for operating the auxiliaries, that furnished by the evaporator being insufficient. The 2,400 pounds of live steam, *C*, entering the evaporator made 2,160 pounds of evaporator steam, *D*, under a pressure of 80 pounds, and this quantity mingling with the 1,490 pounds by-pass steam, *B*, gave a total of 3,650 pounds, *F*, the steam

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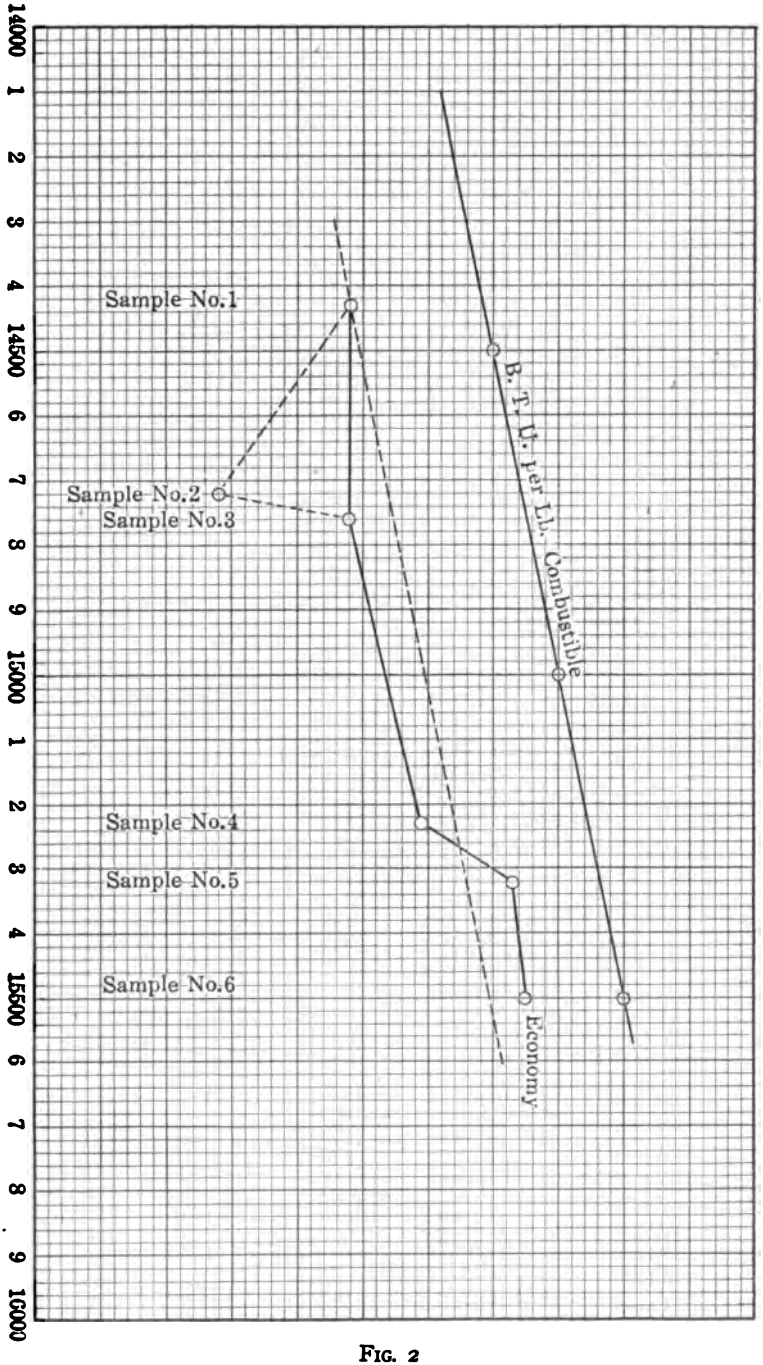

FIG. 2

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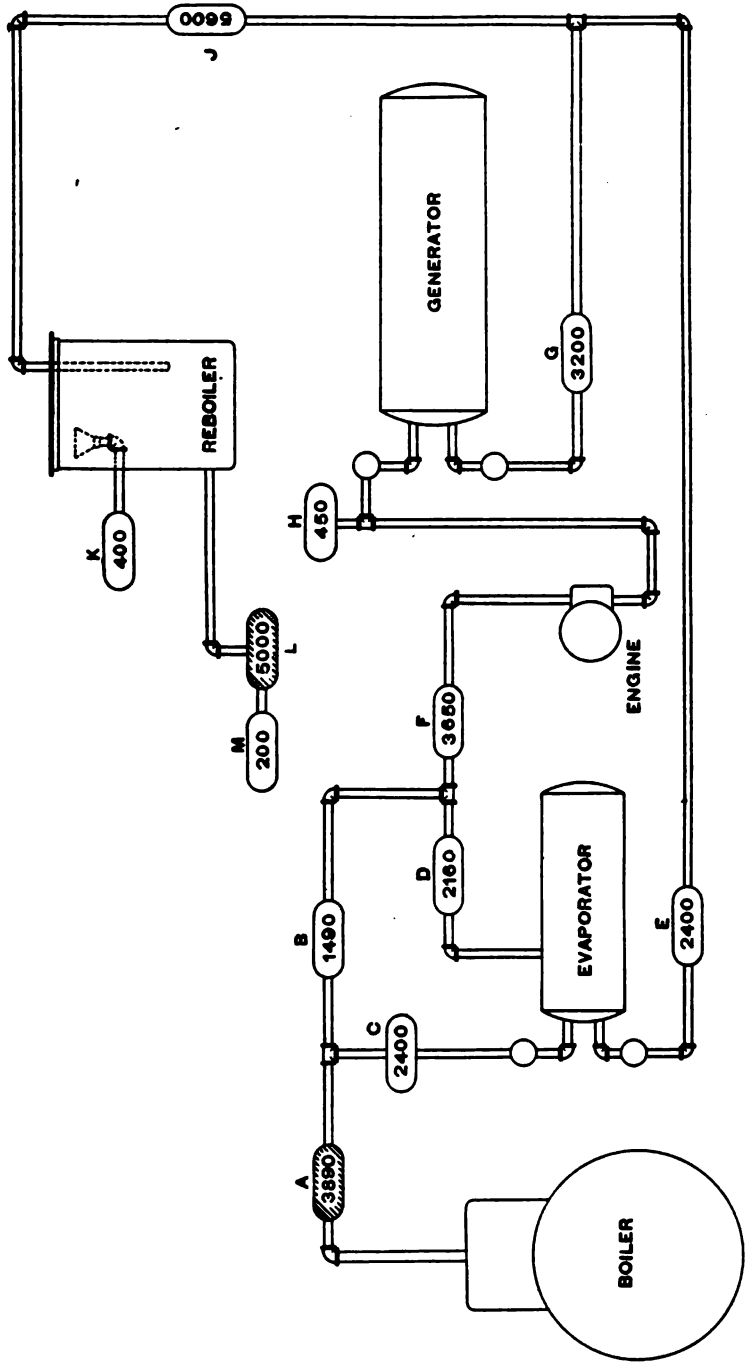

FIG. 3

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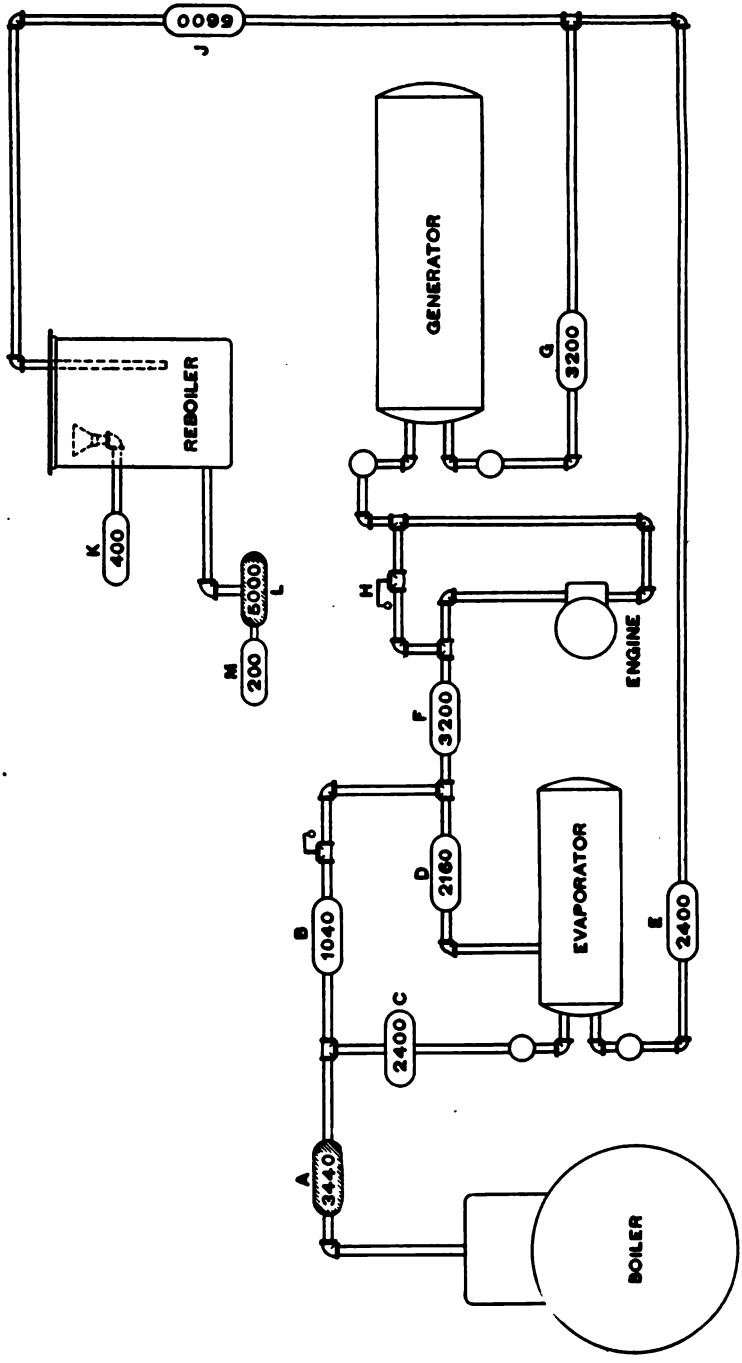

FIG. 4

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required to operate the auxiliaries. Part of the exhaust steam from these auxiliaries—namely, 3,200 pounds—entered the generator, and the balance, 450 pounds, *H*, was discharged into the atmosphere. The live steam going to the evaporator was condensed therein and formed 2,400 pounds of condensation, *E*, which, added to the condensation of the generator, made a total of 5,600 pounds per hour, *J*. Of this quantity, 5,200 pounds went to make the ice, 200 pounds, *M*, being the thawing loss, while 400 pounds, *K*, was lost at the skimmer and reboiler. The condensation from the generator was accurately determined, not only by the Venturi meter, but also by calibrating the pump which took the condensation from the generator. The evaporator condensation, which was metered by means of a Venturi meter, checked very closely with the amount of steam shown by the General Electric steam flow meter. The loss of exhaust steam at *H* was checked by means of a condensing coil and the water weighed. Points *B*, *K* and *F* were estimated.

Had this test been run earlier in the year, when the steam consumption of the air compressors was normal, the condition shown in Fig. 4 would have resulted. The steam loss at *H* of 450 pounds would have been saved, and in this case the total amount of steam that the boiler would have had to furnish would have been 3,440 pounds in place of 3,890 pounds.

From the above data it will be seen that under conditions shown in Fig. 3, with the steam consumption of 3,890 pounds, the plant made 5,000 pounds of distilled water ice, or the economy of the plant was $5{,}000 - 3{,}890 = 1{,}110 \div 3{,}890 = 28.6$ per cent. more distilled water ice than the boiler evaporation of the plant. With conditions obtaining as indicated in Fig. 4, the economy of the plant would be $5{,}000 - 3{,}440 = 1{,}560 \div 3{,}440 = 45.3$ per cent. better than the boiler evaporation.

It is never possible in practice to furnish the auxiliaries with just the amount of steam that is required by the generator. It is, therefore, always advisable to figure these auxiliaries on a liberal basis, keeping their total consumption below that of the generator. Then, if necessary, make up the quantity of steam required by the generator through the by-pass valve, *H*, Fig. 4.

The above diagrams are for the purpose of illustrating a method for determining the boiler evaporation with the evaporator system, and items 8, 9, 10 and 11 on the efficiency diagram have been covered. We still have before us the problem of the boiler efficiency. It is a known fact that, with a poor boiler plant, an indifferent quality of coal, a dirty boiler and careless firemen, the efficiency of a boiler may

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fall as low as 4 pounds of steam per pound of coal, or even lower. On the other hand, there are plenty of tests that have shown under actual operating conditions an economy as high as 10 pounds of steam per pound of coal. In case of a boiler evaporation as low as 6 to 1, the efficiency of the plant, with operating conditions as shown in Fig. 3, would be 7.7 pounds of ice per pound of coal. While, with a boiler evaporation of 10 to 1, the efficiency of the plant would be 12.8 pounds of ice per pound of coal with conditions shown in Fig. 3, and 14.5 pounds of ice per pound of coal with conditions shown in Fig. 4. In a great many cases the contractor may have little to say about the boiler, water treating system, etc., as that portion of the plant is often already in service. Over the other two items, quality of coal and firing, he may have still less control.

It would seem, therefore, owing to the constant demand for efficiency and low cost of production in every branch of trade, that a basis of economy should be adopted for ice plants. It appears that a guaranty based on the boiler evaporation of a plant is a logical one, and is absolutely fair to both the contractor and the purchaser. The writer would, therefore, suggest that this Society give this subject careful consideration for the purpose of establishing a standard basis on which a coal efficiency guaranty can be made.

DISCUSSION.

Peter Neff.—I would like to ask Mr. Hiller one question that I may have misunderstood in the diagram. When you gave the line of the B. t. u.'s and projected the line parallel to it below, did you intend that to be brought down parallel, or did you intend to give an economy curve?

N. H. Hiller.—That is brought down parallel so that you can see what the actual performance of the plant was in proportion to the B. t. u. in the coal. The tables show the fixed carbon to be from 48% to 60%, but when you come to allow for the moisture and ash you will find there is only 3 or 4 per cent. difference in the fixed carbon, and so the efficiency of the furnace does not affect the tests.

President Shipley.—Mr. Hiller, can you give us the price of the coal used?

N. H. Hiller.—I have the cost here. One coal, the cheapest coal burned, Indiana No. 4, cost $1.80 a ton. That made the ice cost 20.3 cents per ton. Another coal, which was from West Virginia, cost $1.95 a ton, which came out 19½ cents per ton of ice. A Kentucky coal came out 22½ cents.

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President Shipley.—Was that price on the cars or in the bin?

N. H. Hiller.—That's car price, delivered at the plant.

Peter Neff.—Short ton or long ton?

N. H. Hiller.—I suppose that is the long ton; I don't know; how do you sell soft coal?

Peter Neff.—Short ton.

N. H. Hiller.—Well, then, this is the short ton price; that was the price billed to the owner. Of course, in the anthracite regions we get the long ton.

Charles H. Herter.—I am surprised to see that the steam for the auxiliaries was taken out of the evaporator at 80 pounds' pressure.

N. H. Hiller.—That is the basis of the system, to get distilled water with as little cost as possible. In order to accomplish that, the difference in the sensible heat of steam at 125 pounds pressure and that of 80 pounds pressure is lost. We are thus able to evaporate very nearly the same amount of steam out of the water in the evaporator as we put live steam in the coils; thus we lose the sensible heat between 354 degrees and 324 degrees, namely, 30 degrees. The plant auxiliaries are so proportioned that they can operate with steam under 80 pounds pressure, there is no loss in economy there, and the exhaust of these auxiliaries is used in the ice machine.

President Shipley.—This particular method, as you may know, is not a new one. It was tried a number of times, especially by Alfred Siebert, of St. Louis. He put up several plants on this principle, where they run compound engines from the steam, and he used this method for running auxiliaries. But Mr. Hiller's adaptation of this system to the absorption plant is new, so far as I know.

Henry Torrance, Jr.—What steam pressure did he start with?

Edward N. Friedmann.—150 pounds to start with.

Henry Torrance, Jr.—Where did he strike the snag?

Edward N. Friedmann.—I don't know that he struck any snag; it was about twelve years ago.

President Shipley.—What I know about that particular point is this, that Mr. Siebert sold the York Manufacturing Company a layout for one of our plants for a certain amount of money. He claimed that we were going to get all sorts of results from it, but I could not see where we were going to make any money on it, so we did not use it. He had a plant working in St. Louis that he wanted me to go and see, but I didn't go. He was not the originator of the idea; it had been used in Germany.

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Henry Torrance, Jr.—Is Siebert's plant running now?

President Shipley.—No.

Henry Torrance, Jr.—Why? Did he wreck his engine?

President Shipley.—Was that your experience?

Henry Torrance, Jr.—No.

President Shipley.—What made you think he wrecked his engine?

Henry Torrance, Jr.—I was wondering why he didn't succeed in his plant.

President Shipley.—The economy of a plant of this kind depends, in the first place, upon the economy of your prime mover, which is the generator of your refrigerating plant. Where this part of the plant requires less steam to operate it than is required to fill the cans which the plant will freeze, you can use apparatus of the evaporator type to supply the additional distilled water, if you see fit. With a compression plant you could eliminate the question of driving by steam entirely, as is done in plants that are driven by electricity. We don't want this to go down on our records as being a world-beater. It is a good plant, there is no question about that, but we don't want to look at it as if nothing else could be done along this line. It is one of the methods of getting the additional distilled water, and is a mighty good one, provided your evaporator don't cause you too much trouble. Now, I shouldn't wonder but that some of the troubles that Mr. Torrance had was with the scaling of the tubes in the evaporator, because the water in that territory is bad for scaling. I think evaporators in that territory are bad fellows to loaf with.

Peter Neff.—I would like to ask Mr. Hiller if he has an analysis of the water used?

N. H. Hiller.—No. There is a water treating plant in connection with the boiler plant. It was in the old ice plant that they had there originally. I do not really know the name of the treating plant, but it was a small one, and the water coming in to both the boiler and the evaporator was turbid at times. It was a continuous water treating plant and the water did not thoroughly clarify before it was fed.

Henry Torrance, Jr.—As regards this scaling bugaboo, we have that in all boilers. It is easier to take tubes out of an evaporator than out of a boiler. As a matter of fact, if a layman looked at a plant of this kind he would say, "I can see how you can get along with that evaporator, but I am afraid your boiler will give you trou-

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ble." A boiler, as a general proposition, is much harder to keep clean than an evaporator.

F. W. Pilsbry.—My experience is that with the evaporator they generally put in a single unit, and when it is out of business the plant is out of business.

Henry Torrance, Jr.—It is quite easy to make the evaporator in two sections, and, generally, if you have two evaporators, each equal to half of the load, it will answer the purpose.

President Shipley.—Mr. Torrance says an evaporator is as easy to take care of as a steam boiler as regards scaling troubles, but we should not let him get away with it. We all know that a boiler is built so that it can be taken care of easily, especially as regards ordinary scaling troubles. Those of us who have operated evaporators, no matter who made or designed them, know what a job it is to take out the scale and mud. The man that sells them will tell you that all you have to do is to change the temperature of the tubes and the scale drops off, but if you try that a few times you will find how near his talk is to the truth. You must understand that with an evaporator you can't blow out and keep the scale from forming on the tubes as easily as you can in boilers, because every time you blow out an evaporator you waste a large portion of your work; whereas, with your boiler, you are blowing out cold water. Those of you who have run these different kinds of apparatus know these facts as well as I do. At the present time our company is having troubles of this kind. At this moment we have one lot of evaporators that will fill about two cars coming back on our hands because it was not easy to keep them from scaling, but the boilers on this same plant are all right.

Henry Torrance, Jr.—What kind of boilers? Horizontal tubular boilers?

President Shipley.—Yes.

Henry Torrance, Jr.—How do you keep the scale out of them?

President Shipley.—Clean them out. You can use a compound and blow them out; but you must understand when you use the evaporator that everything that goes into it stays there until you shut that evaporator down and clean it out. You can't blow it out every hour or half hour as you can a boiler, without losing a tremendous lot of power.

N. H. Hiller.—The plants under this system are all single-effect evaporator plants, and the troubles would be in proportion to the number of effects. The fact is that of a number of plants that we

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have put out in the last three years I know of one only that shuts down once a month to clean the evaporator; they have no water-treating plant, and they clean the boiler at the same time. There is no very great difficulty in cleaning the evaporator; it cleans quicker than the boiler; you take the coils right out, scale them and put them back while you are waiting for the boiler to cool off. In other plants where we have two evaporators, each with half capacity, we seldom find it necessary to run both, but where we do, they usually have a water-treating plant. Where they don't have a water-treating plant it is a different proposition; but where a man is going to make ice and make it for as little money as he can he will usually invest in a water-treating plant, as it pays for itself in the saving in coal and repairs.

R. E. Bridgette.—I would like to ask what kind of evaporators these are?

N. H. Hiller.—Similar to ammonia generators with built-up coils.

Peter Neff.—Water inside of the tubes?

N. H. Hiller.—No, steam inside of the tubes.

Henry Torrance, Jr.—I haven't quite got it through my head why you can't blow out an evaporator the same as a boiler, if the water comes from the same pump and the same well. This boiler feed pump feeds the boiler and the same line leads to the evaporator; there is no more heart's blood in one than in the other; you can blow out the evaporator at the same time you do the boiler.

President Shipley.—How many times did you blow out this evaporator during the test? You don't know that, do you? Just tell us that and then we will answer the other question.

N. H. Hiller.—It was blown down twice in every twelve-hour shift, or every six hours.

Henry Torrance, Jr.—As I said before, the evaporator is the easier proposition. In the case of a horizontal tubular boiler you have got tubes expanded into holes, and a man can't get inside to scrape out the scale, but in the case of an evaporator you have got the scale on the outside of the tubes, and if you get real mad you can take off the head and pull out all the coils and then tackle the outside, whereas you can't tackle the outside of the tubes in the boiler and can't take the tubes out.

President Shipley.—I think this Society would like to know how many square feet of surface you have in that evaporator; that's the bug-a-boo. If you want to know, that is where Siebert fell down.

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The temperature range in the evaporator was so much less than that in the boilers that it was necessary to have a tremendous apparatus. You haven't about 2,000 degrees on one side of the surfaces and 300 or 350 on the other, in your evaporator, as you have in your boiler. That fact has to be taken into consideration, and the difference in the size of the plant required is material. It costs us more money to put up such a plant than to put up an ordinary plant, and the cost of upkeep is more. That is what made Siebert's apparatus a failure.

Peter Neff.—Boilers are not easily cleaned. The only way to prevent boilers from scaling is to put in a softening plant. All these matters interest the purchaser more than the engineer. It is a question of cost, and the cost of the appliance that is necessary to protect the different parts of the apparatus goes to make up the charge against the cost of the ice production; that is the stumbling block. If you go to a man and say that he can keep his boilers perfectly clean if he puts in a water softening plant he will ask, "What is it going to cost?" You figure the cost and he says, "I will take my chances on cleaning the boiler out." I don't think anybody who has had any experience in those things fails to realize that evaporators will scale the same as boilers, and that they are troublesome, to say the least, to clean; so that, in addition to putting in your evaporator system, which adds to the cost in addition to the boiler, you are almost compelled to put in a water softening plant, which also adds to the cost.

If you could get down to the cost of these things relative to the cost of the ice produced it would be, to my mind, a thing that would interest the trade. The economies that can be realized by different appliances are intensely interesting, and if they can be operated without increasing the cost too much, the saving will ordinarily cover the extra overhead charge; but in most cases, in my experience, in figuring the increased cost necessitated by these economies, it has not shown a profit to the purchaser in the ice produced, and that, when all is said and done, is the crucial question, and it is one we have got to face in dealing with the trade in general.

N. H. Hiller.—The very questions Mr. Neff brings up are the ones supposed to be covered by the second portion of the efficiency diagram and are very important; there is no doubt about that, and those are the items that vary with the cost of the plant, as well as the conditions. It requires a trained engineer, or somebody whose powers of penetration reach beyond the ken of the ordinary purchaser, to decide whether it is advisable to put in a less efficient type

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of plant in order to save the first cost, or a more efficient type and try to make up the difference in first cost by decrease in operating expenses. As to the maintenance of an evaporator system, if we didn't have an evaporator we should have to have steam condensers, and my experience with steam condensers is that the depreciation is fully as great if not more than that of an evaporator system. As to surface in the evaporator, in this particular plant there was 125 pounds' head pressure and 80 pounds' evaporator pressure; if your conditions were such that you had to run on a difference of 15 degrees you would have to have double the surface. The surface of every evaporator has to be proportioned to conform to the conditions of the plant.

Theodore Kolischer.—I would also like to ask Mr. Hiller and Mr. Torrance whether, in this particular plant, you were troubled with any discoloration in the ice?

N. H. Hiller.—No, none at all. I think once or twice there were troubles, such as are encountered in an ordinary plant, but I was there four days and the ice was very good.

Peter Neff.—How long was this test in operation?

N. H. Hiller.—It started in April and lasted through the summer into August. This last test was during that hot spell right around Labor Day.

Theodore Kolischer.—How frequently was the evaporator cleaned; either blown or totally cleaned?

N. H. Hiller.—The evaporator has never been opened that I know of since it was installed. I won't say that, either, because it has been opened in the last month or so, but up to that time it was not opened, but was blown every six hours.

Theodore Kolischer.—During the summer the evaporator was not opened up, not thoroughly cleaned, but you relied mainly on the blowing out?

N. H. Hiller.—Absolutely.

F. W. Pilsbry.—I would like to ask the cause of the discoloration?

N. H. Hiller.—I don't know. During the time I was there I didn't see any.

F. W. Pilsbry.—No more discoloration than in the ordinary plant?

N. H. Hiller.—I didn't see any. The ice looked good during the test. The only thing is, like every other plant, you don't want to fill the evaporator up too full of water any more than you would a

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boiler, because if you do it will foam, and the separator may not take care of the entrainment. These are things that come under the eye of the operating engineer.

Edward N. Friedmann.—Were the boilers cleaned during the summer?

N. H. Hiller.—They had two boilers and changed every two weeks. I don't think they put anybody in to clean them, though possibly they did.

Edward N. Friedmann.—What was the proportion of the amount of water used by the evaporator and the boiler?

N. H. Hiller.—The boiler used 3,800 pounds and the evaporator 2,100.

Edward N. Friedmann.—For the same amount of water you would naturally get the same amount of scale?

N. H. Hiller.—The same in proportion, but I think the water was treated pretty well. There wasn't very much scale; there was mud; the treatment seemed to take care of the scale in good shape and the mud was blown out. This was a single-effect evaporator. We have never tried the multiple effect; with this system there would be no economy in it. The only time that it would help would be when the refrigerating unit had an economy of less than 45 pounds of steam per hour per ton of ice. If you can get your refrigerating unit down to less than that, the multiple effect would come in to advantage. It requires 93 pounds of distilled water per hour per ton of ice; of that, 83 pounds goes into ice and 10 pounds is lost at the dump, in the reboiler and skimmer. Taking half of 93 gives 46½. If the economy of the generator is 45 pounds, the evaporator would be using 48 pounds in order to give 45 pounds of evaporator steam. When you get below that you would have to use multiple-effect evaporators, but until you do, a single-effect evaporator answers the purpose.

Edward N. Friedmann.—I have run plants with both single and multiple effect evaporators, and I must say that the scale did make trouble. In the old type evaporator you could get the scale off the tubes by making them good and hot and then putting cold water on, but when the scale came off it went into the circulating pump and got into the overflow pipe, so that, after having a considerable trouble with that for a year or two, I constructed a screen to keep it from getting into the circulating pump, but this meant opening the evaporator and stopping it half a day or so to remove the scale from the screen.

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N. H. Hiller.—The evaporators used in the chemical industry have their tubes proportioned so as to give a forced circulation in the evaporator, and they manage to get along without any scaling of tubes or any trouble of that sort, even with all sorts of concentrated alkalies.

Irving Warner.—I know little or nothing about distilled ice-making and absorption systems, but, looking at this diagram of Mr. Hiller's, a thought occurs to me which may throw a little light on the situation, and if any of my thoughts or deductions are wrong I would like to be corrected promptly for my own benefit. I notice in this diagram, Figure 3, that we have a more or less complicated system of pipes, evaporators and re-boilers, the object of which apparatus is, of course, to get as much water, represented by E-2,400 pounds, which is good distilled water without any oil in it, as possible, and then a further amount of water, G-3,200 pounds, which is good distilled water, except that it has a little oil in it. Now, oil seems to be the bugbear. Why cannot the refrigerating engineers substitute in place of this a small turbine unit which will run without oil and which will run with an economy not greatly inferior to ordinary small high speed engines, and eliminate the evaporator, letting the exhaust of the turbine engine go to the generator, so that the condensation therefrom would be good distilled water, free from oil? That would also allow you to eliminate the re-boiler at once. The only possibility of error in my deduction, it seems to me, is that perhaps the turbine economy is so inferior that the amount of steam used in the generator would be entirely out of proportion to the amount of distilled water desired for the ice. Can Mr. Hiller or anybody else who has had experience with these turbines enlighten me on this subject?

N. H. Hiller.—That is quite feasible and is being done in Lexington, Kentucky, at the Kentucky Traction and Terminal Company's plant. There the turbine operates the water circulating pump for the complete plant, and the exhaust is used in the generator of the ice machine. In that way they eliminate the oil, but you wouldn't get the distilled water without either the use of an evaporator or a turbine, the consumption of which would be equal to the total ice required. In practice, the construction of the plant is somewhat different from that shown on the diagram. The reboiler and the skimmer are separate shells, and the distilled water from the evaporator goes to the skimmer, while that from the generator goes to

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the reboiler. In making can ice you will find that it is advisable to reboil the water whether you have any oil in it or not.

John C. Sparks.—In the operation of two evaporating systems I know quite well, one in Key West and one in Albany, the scaling of the evaporator, that nearly always occurs, can be regulated by blowing off twice a day. The ordinary engineer won't do this, but if he would he wouldn't get the scale. In the plants just referred to no trouble from scaling is experienced now.

N. H. Hiller.—That's just what we did, blowing off twice in a shift.

President Shipley.—In regard to the reboiler, you seem to take it that, unless there is oil in the ice, reboilers are not necessary. The principle of a reboiler is to drive the gases out of the water. The elimination of the oil is only an incidental part of the work of the reboiler. We have had a deal of experience with evaporators all over the country. Evaporators that work in one part of the country won't work in another. Blowing out every six hours is all right in some places, but not in others. You can't make any hard and fast rule, but must find out what is necessary to do with the water you are using. That's where you have about a year's work on most of these plants before you say "Good-bye" to them, even if the other fellow is willing to let you go then.

Edward N. Friedmann.—Just one more question; how about the boiler feed water heater? Did you have a heater?

N. H. Hiller.—There is no steam, either live or exhaust, used to heat the feed water. It is heated with a heat exchanger in three stages, using first the distilled water coming from the reboiler; next, the condensation from the generator, and, third, the evaporator condensation, which gives a feed water temperature usually above 230 degrees.

Edward N. Friedmann.—Did you find any scale in the heater?

N. H. Hiller.—Yes, one of those tests, No. 2, shows there was difficulty with the feed water heater, and they cleaned it out after that test.

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No. 105

ATMOSPHERIC DEHUMIDIFYING

By J. I. Lyle, New York, N. Y.

(Non-Member of the Society)

The heat removed in cooling air from the dry bulb to the wet bulb temperature is exactly equal to the heat required to evaporate the water necessary to produce saturation at the wet bulb temperature. From this it may be seen that the really important consideration in the cooling of air is the wet bulb temperature. If the wet bulb temperature is known, the humidity, or the dry bulb temperature, is of no real importance and is not needed for the purpose of calculation.

The following extracts, Table I, from a series of tests made by W. H. Carrier are very conclusive proof of the above statements:

TABLE No. 1.

Air Temperature, Degrees Fahrenheit.			Water Temperature, Degrees Fahrenheit.	
Entering.		Leaving.		
Wet Bulb.	Dry Bulb.	Saturated.	Entering.	Leaving.
80	81.	61.1	58.8	64.4
80	84.	60.8	58.8	64.4
80	87.	61.1	58.8	64.3
80	84.	60.9	58.8	64.3
80	90.5	60.9	58.9	64.1
80	93.5	60.8	58.8	64.1
80	96.	60.7	58.8	63.9
80	98.	60.8	58.9	64.0
80	104.5	60.7	58.9	63.9
80	107.	61.2	58.9	64.0

In the above test, only cold water was used and the moisture content of the atmosphere was reduced.

The following test, Table II, shows the effect when adding moisture:

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TABLE No. 2.

Air Temperature, Degrees Fahrenheit.			Water Temperature, Degrees Fahrenheit.	
Entering.		Leaving.		
Wet Bulb.	Dry Bulb.	Saturated.	Entering.	Leaving.
75	77	91.5	110.1	88.9
75	80	91.5	110.1	88.4
75	90	91.5	110.1	88.5
75	95	91.3	110.1	88.4
75	100	91.3	110.1	88.4
75	105	91.5	110.1	88.4

The dry bulb temperatures were varied from 77 degrees Fahr. to 105 degrees Fahr., but the wet bulb temperatures were maintained constant at 75 degrees. The flow of water was constant, as was the air handled. It will be noted that: First, the leaving temperature of air was practically constant in all cases, although in three cases the air was heated, and in the other three it was cooled; and second, the temperature drop of the water was also practically constant, showing that the heat removed was the same in each case.

In contrast with the above it is interesting to note in Table III the effect of varying the wet bulb temperature with the dry bulb temperatures constant. Here, although the entering wet bulbs are only

TABLE No. 3.

Air Temperature, Degrees Fahrenheit.			Water Temperature, Degrees Fahrenheit.	
Entering.		Leaving.		
Wet Bulb.	Dry Bulb.	Saturated.	Entering.	Leaving.
75	90	95.7	110.1	93.2
80	90	97.8	110.1	94.1

5 degrees apart, there is a difference in the final temperatures of 2.1 degrees Fahr. That the amount of heat removed was different is shown by the difference in the rise in temperature of the water.

The usual way of calculating the amount of heat to be removed in the cooling of air is to estimate separately the sensible heat of the air cooled, the latent heat of condensation, and the heat for

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cooling the condensed liquid. This method, however, admits of considerable error. In the first place, the specific heat of air is a variable, and, for ordinary temperatures, recent investigation has shown it to be approximately 0.241 instead of 0.2375, which has been so generally used. In the second place, the latent heat of condensation is also a variable, changing with each degree change in the temperature.

A much simpler, and at the same time a very accurate, method of calculating the heat, is to make use of a curve of total heat of saturated air, which was described in a paper by Willis H. Carrier before The American Society of Mechanical Engineers. Mr. Carrier says: "The cardinal principle of this method is, that for a given temperature of evaporation—that is, for a given wet bulb temperature—a pound of air contains a fixed and definite amount of heat, regardless of the dry bulb temperature or of the moisture contents. This means that the wet bulb temperature is the rational and convenient measure of the total heat contents of the air, both latent and sensible. For example, an ordinary recording thermometer with the bulb covered with a wetted wick, over which a current of air is circulated, could be made to record B. t. u. contents per pound of air by graduating the record in terms of B. t. u. instead of in degrees temperature. Consequently, in dehumidifying the maximum refrigerating load will occur at the maximum wet bulb temperature, relation of dry bulb temperature to moisture contents being immaterial."

This curve is shown in Fig. 1, and is based on the weight of a pound of dry air, which is saturated at the given temperature. By the use of this curve, by taking the difference between the total heats of the final temperature or dew point to which the air is cooled, and the total heat of the air saturated at the entering wet bulb temperature, the amount of heat to be removed is very quickly obtained. The number of cubic feet of dry air and dry air saturated per pound are also shown by the curve, which adds to its value for practical use.

It will be noted that the ratio of cubic feet per pound of dry air for the various temperatures is indicated by a straight line, while the cubic feet per pound of dry air saturated is represented by a curve.

The number of cubic feet of the mixture of air and vapor when not saturated may be found by taking the difference between the number of cubic feet for dry and saturated conditions and multiplying this difference by the percentage of saturation of the mixture, and adding this to the cubic feet per pounds of dry air.

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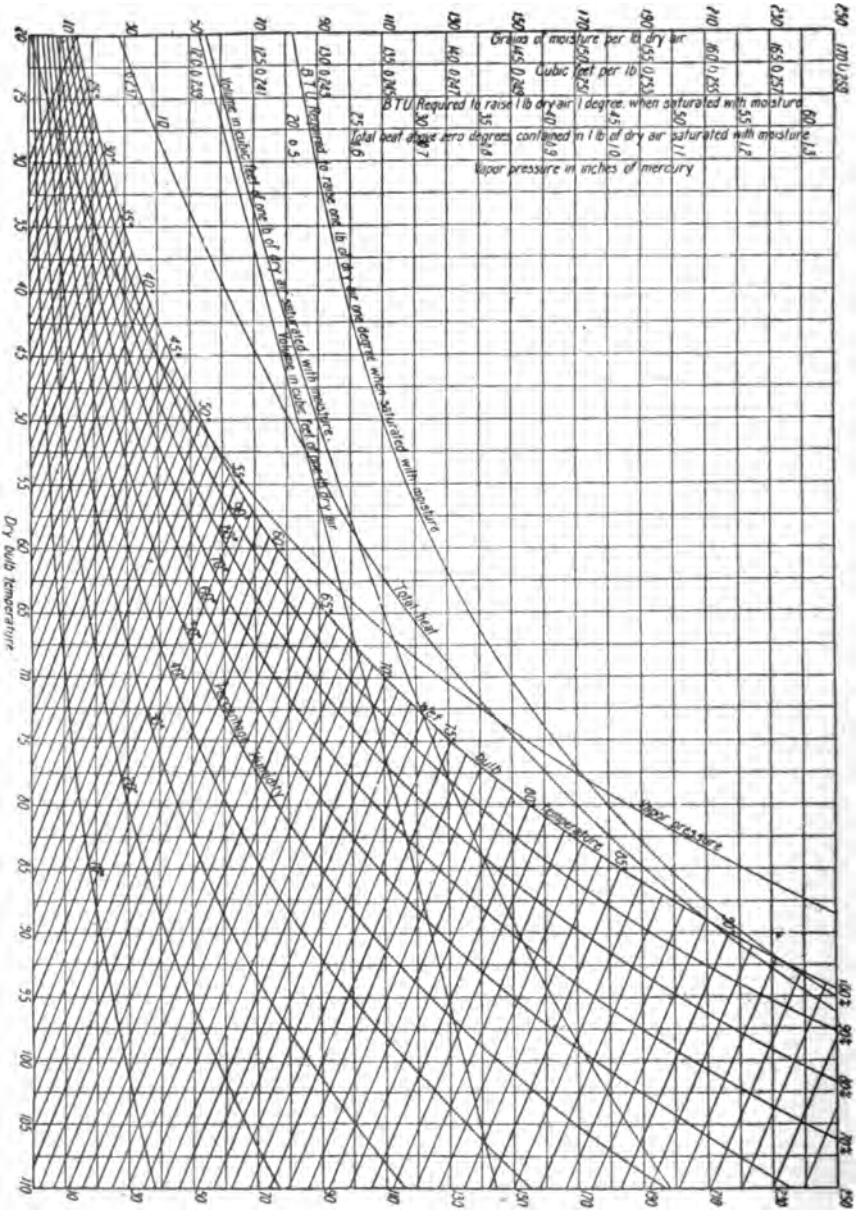

FIG. 1.—PSYCHROMETRIC CHART. COMPILED BY WILLIS H. CARRIER.

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To illustrate: Required a plant of a capacity of 13,000 cubic feet of dry air per minute, which enters the apparatus at a temperature of 90 degrees with 60 per cent. relative humidity. By referring to the chart it is found that at 90 degrees Fahr. 14.54 cubic feet of dry air is saturated per pound. Since there are 13.86 cubic feet of dry air per pound, the difference, $14.54 - 13.86 = 0.68$ cubic feet, is the increase in volume due to the water vapor necessary for saturation. As the mixture is 60 per cent. saturated, $0.68 \times 0.60 = 0.408$, the number of cubic feet of vapor in the mixture per pound of dry air, and $0.408 + 13.86 = 14.268$, the number of cubic feet of the mixture at 90 degrees Fahr. and 60 per cent. relative humidity per pound of dry air.

$$\text{Then } \frac{13{,}000}{14.268} = 911 \text{ pounds of dry air.}$$

To procure the total heat from the chart, let it be assumed that the air entering at 90 degrees Fahr. and 60 per cent. humidity must be reduced to 50 degrees Fahr. It will be found that 90 degrees and 60 per cent. relative humidity corresponds on the chart to a wet bulb temperature of 78¼ degrees Fahr. Now, by following along the oblique 78¼ degree Fahr. line to the curve of saturation, and then vertically to the total heat curve, the total heat is found to be equal to 40.75 B. t. u. per pound. By finding 50 degrees Fahr. on the saturation curve and tracing it vertically we find its total heat is 20.2 B. t. u. Now, $40.75 - 20.25 = 20.5$, the number of B. t. u. per pound of dry air, and 20.5 (B. t. u.) $\times$ 911 (pounds) $= 18{,}675$, the number of B. t. u. to be removed from 13,000 cubic feet of air at 90 degrees Fahr. and 60 per cent. relative humidity, in order to reduce it to 50 degrees Fahr. and saturation.

Description of surface types of apparatus for dehumidifying would be out of place here, as you are all very familiar with air bunkers, brine and direct expansion coils, dry and flooded. A description, however, of types of spray apparatus, which is becoming more widely used, may be of interest. Many seem to think the application of a direct spray to air for the purpose of dehumidifying is at least not orthodox. Atmospheric humidity is nothing more nor less than a mechanical mixture of steam at low temperatures and air. It is subject to exactly the same physical laws as steam at higher temperatures, with the exception that the heat of the air under certain conditions modifies these laws.

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Jet and barometric steam condensers were the first types used, and are still more extensively used than the surface type. The use of cold water or brine in direct contact with the air to be cooled is not very new, but the experimental work necessary to enable machines of high efficiency to be designed has only recently been carried out. Apparatus employing the spray has now been standardized and is regularly manufactured.

The spray method possesses several advantages over the coil surface method.

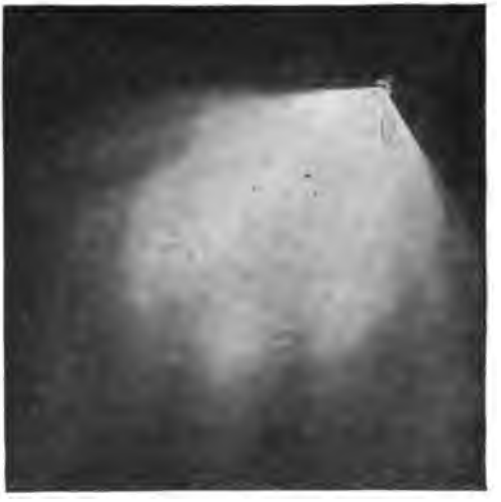

FIG. 2.—NOZZLE IN OPERATION.

First, there is no frosting with the entailed necessity of thawing off.

Second, in compression plants, as the air and water can be brought in a single stage to the same temperature, a higher suction pressure can be maintained.

Third, the air is thoroughly cleansed by the washing.

Fourth, more accurate regulation is permissible, and automatic control, which is very simple and positive, may be employed.

Fifth, much less space is required.

Sixth, where well water is available in sufficient quantities, a considerable work can be done without refrigeration.

In all spray machines the air to be treated is passed through a chamber in which are uniformly distributed a number of nozzles, from which a very finely atomized spray of water or brine plays in direct contact with the air. At the exit the air comes in contact

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with a set of corrugated eliminator plates which remove all free moisture.

The form of the nozzle, Fig. 2, is very simple, and depends upon the centrifugal action of the water under a pressure of approximately 25 pounds. The water is discharged in a direction opposite to the air-flow. The nozzles are carried by standpipes and are usually arranged in two or more groups.

The eliminator plates, Fig. 3, are set vertically and spaced to provide air passages of less than one inch in width. As the air passes

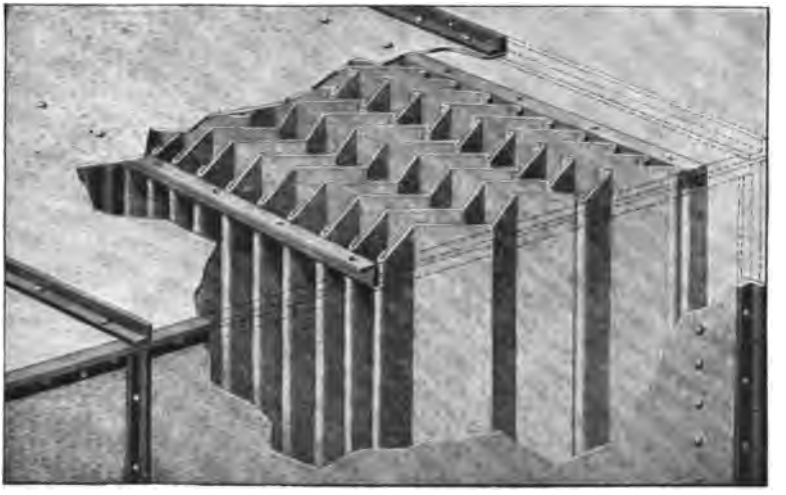

FIG. 3.—ELIMINATORS FOR REMOVING ENTRAINED MOISTURE.

between these plates, and is baffled from one to another, the free water is thrown down and drains to the tank below.

The amount of entrainment of particles of water is very small, and varies with the range in saturated temperature through which the air passes. Usually a rise of half a degree to one degree in the temperature of the air is sufficient to evaporate these small particles and make them disappear, and the friction of the air in the fan generally employed in such installations is enough to give this temperature rise.

One of the most important items in the use of the spray type of dehumidifiers is the filtering and straining of the water. Many of the so called self-flushing or self-cleaning nozzles have been tried for this purpose, but it seems to be impossible to design an efficient atomizing nozzle of this type. It has always seemed to the author

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that the best way to keep nozzles clean is to prevent them from stopping up by properly filtering the water before it goes to the nozzles, instead of letting the dirt get into the nozzle and then trying to get it out.

FIG. 4.—POT STRAINER.

Fig. 4 and Fig. 5 show two forms of strainers which have been used successfully for this work. The rotary strainer, Fig. 5, consists of a cylindrical screen of very fine copper gauze which, as it revolves, is swept clean by the revolving brush, the dirt going into a separate small tank to prevent it from again entering the water.

FIG. 5.—ROTARY STRAINER.

The simplest form of this type of dehumidifying apparatus is termed the "Well Water Type," as it can make use of cold water from any outside source, either natural from springs or wells or artificially cooled water. It is shown in Fig. 6.

The apparatus shown by Fig. 7 and Fig. 8 is probably of greatest interest, as it is a self-contained machine.

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FIG. 6.—CARRIER WELL WATER DEHUMIDIFIER.

The spray chamber is in the upper part, the lower chamber being used for direct expansion Baudelot coils. The water falls into the upper pan, from which it overflows into the flooding troughs below. The overflow pipes are carried below the water line in the troughs in order to seal them.

The coil chamber is completely sealed from the air chamber so that a leak of ammonia is not transmitted to the air current to be carried to the building. The water cooled by the Baudelot coils falls to the tank below, from which it is drawn by a centrifugal pump and returned to the sprays. If too much cooling is being done a portion of all of the water can be by-passed from the upper pan to the pump, and mixed with enough of the cooled water to give the air leaving the apparatus the required temperature.

The practical limit to which air can be cooled with such apparatus when using water is between 38 degrees and 40 degrees Fahr. If lower temperatures are required it is necessary to use brine instead of water. Where the air treated is to be breathed, or brought in contact with food products, a sodium chloride solution is preferable to a calcium chloride solution, as, with the use of the latter, an

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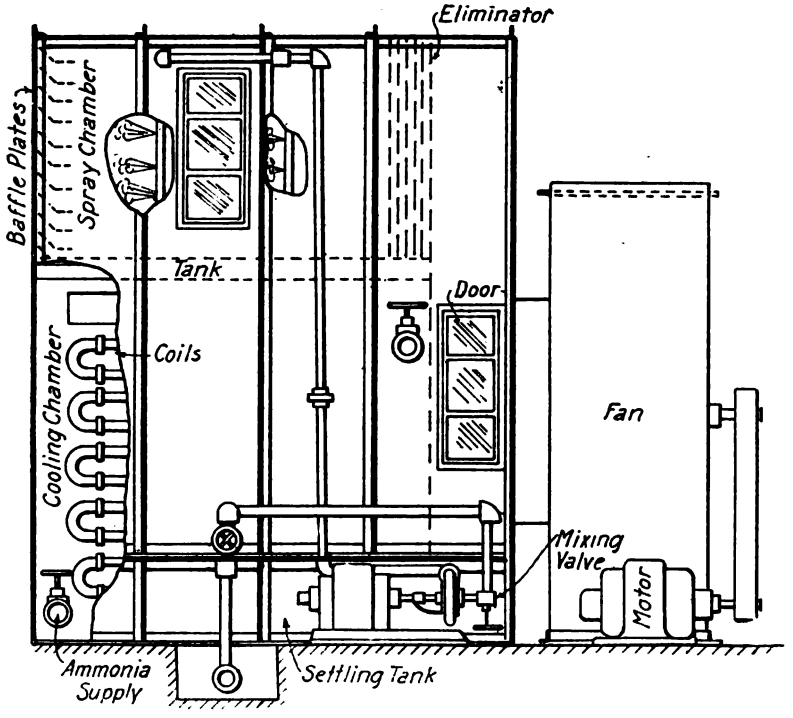

FIG. 7.—SECTIONAL VIEW OF CARRIER SELF-CONTAINED DEHUMIDIFIER.

objectionable odor is always present, notwithstanding that pure calcium chloride does not have an odor, and some manufacturers claim to market a product of very high purity. In the dehumidifying or drying of air for blast furnace work, however, calcium brine seems to give very satisfactory results.

The tower is the most efficient type of cooling apparatus, as it gives a perfect counter-current effect. The latest designs for dry blast plants are making use of this direct spray tower. Water, sufficiently cold to perform a considerable part of the cooling, can usually be obtained from natural sources for the first stage of the work. Even where the water has to be cooled by refrigeration, a very high ammonia suction pressure can be used, thereby greatly reducing the size of ammonia compressor required, and the power consumed.

If the dehumidifying is being done on the suction side of the blowing engine, and much less than two and a half grains of water vapor, corresponding to a dew point of 36 degrees Fahr., is to be

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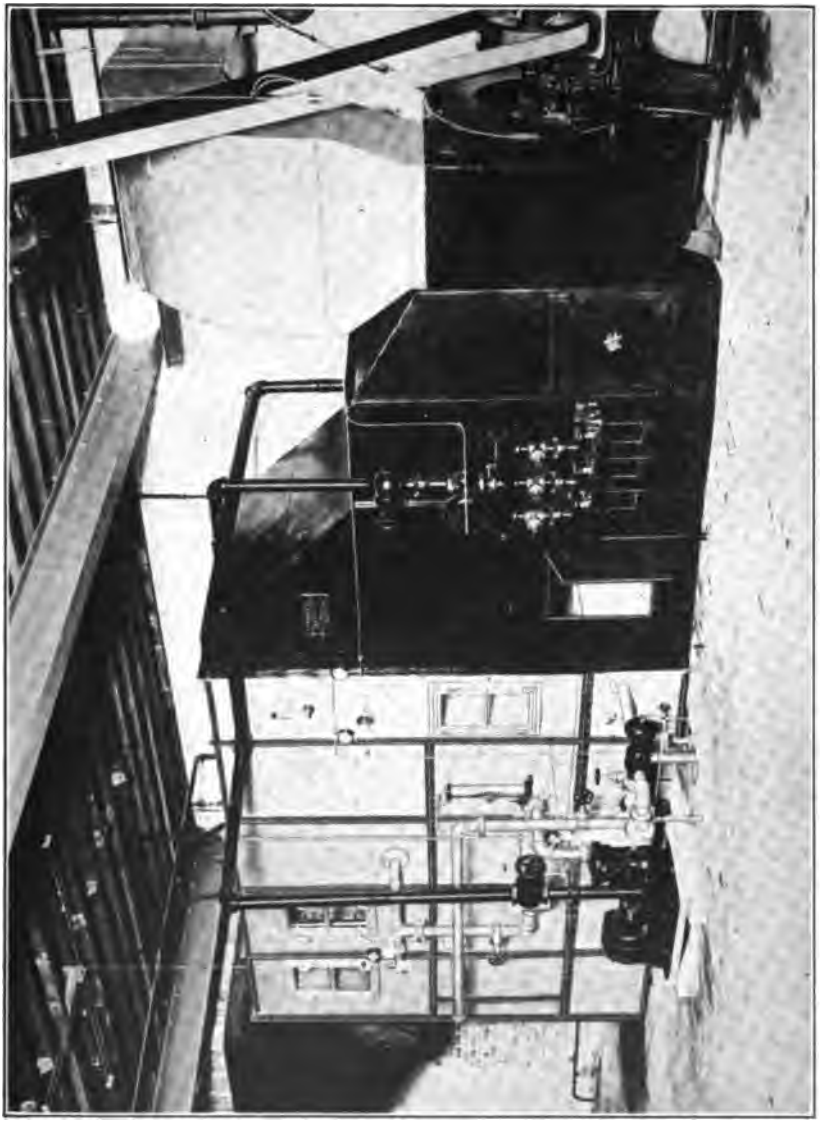

FIG. 8.—GENERAL VIEW OF CARRIER SELF-CONTAINED DEHUMIDIFIER.

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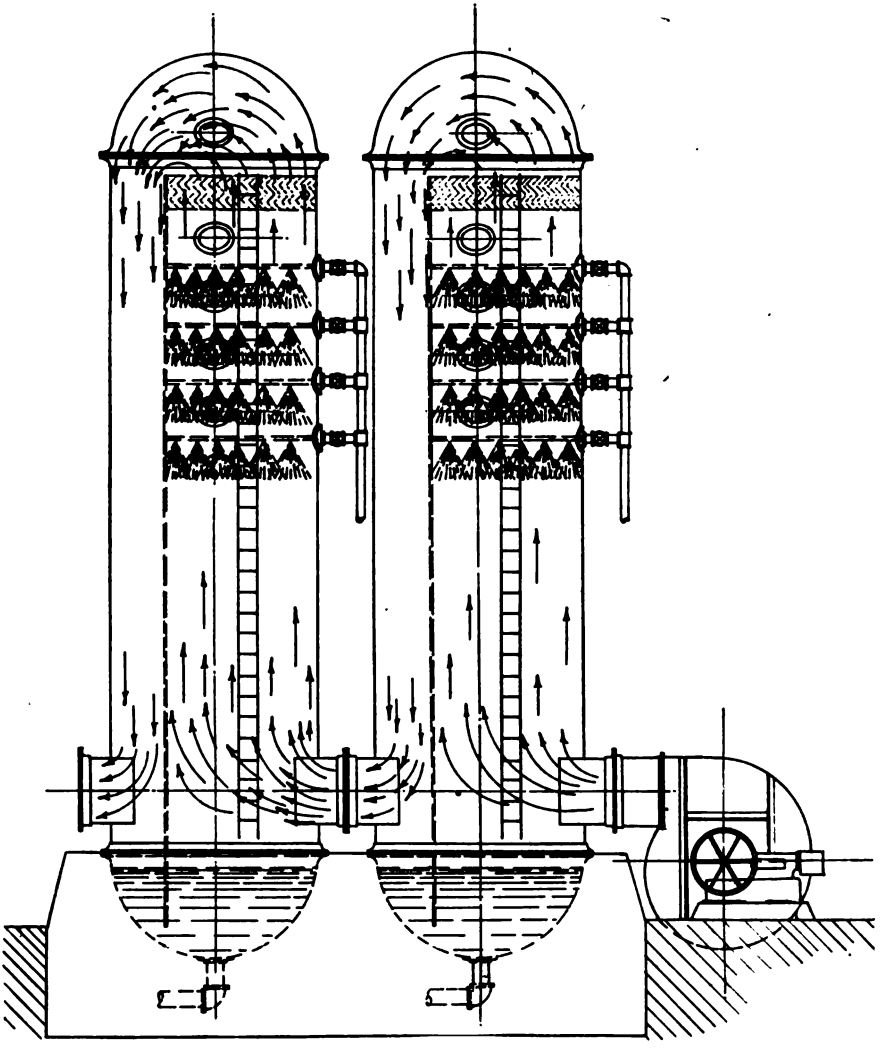

FIG. 9.—DRY BLAST PLANT FOR DEHUMIDIFYING ON SUCTION SIDE OF BLOWING ENGINE.

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carried by the air leaving the apparatus, water cannot be employed in the final stage. In such cases a spray of calcium brine is employed in the final stage. The brine is kept at a constant specific gravity by passing a small portion of it continuously through an evaporator or vacuum pan similar to those used in the manufacture of sugar, an open evaporator being used where live steam is employed for the concentration, and a vacuum pan where exhaust steam is used. By maintaining a constant vacuum, and thermostatically regulating the temperature of boiling, the strength of the solution can be uniformly maintained.

The advantages over the coil or surface type of dehumidifier for this work are: First, reduction in amount of power required; second, reduction of first cost; third, reduction in space required, and fourth, the constant and uniform condition of the air supplied to the furnace.

Fig. 9 shows a set of cooling towers for a dry blast plant for a blast furnace where the dehumidifying is done before the air is compressed, making use of water in the first stage to reduce the air to a temperature of 39 degrees Fahr., and of calcium brine in the second stage to further reduce it to 24 degrees Fahr. and a content of one and a half grains of moisture per cubic foot.

In a large number of dehumidifying installations it is desired to heat the air after the moisture contents have been fixed. In such plants the use of a heat interchanger will effect a considerable economy in operation. This apparatus is really a very simple device, consisting of a number of tubes, on the outside of which passes the incoming air on its way to the final cooler, while the air leaving the cooler passes through the tubes in the opposite direction. The interchangers take up considerable room, but can be made to do 25 per cent. to 35 per cent. of the total work, often effecting a considerable saving in first cost, as well as reduction in refrigeration and power.

Fig. 10 shows an installation in which the spray dehumidifiers use both well water and artificially cooled water. Interchangers are also used. Under maximum conditions this plant operates at about one hundred and ten tons capacity. Thirty-two tons is done by well water, which is procured at 56 degrees Fahr., thirty tons is done by the interchanger, and the remaining forty-eight tons by refrigeration. The artificially cooled water enters the dehumidifiers at 33 degrees Fahr. and the compressors run with a suction pressure varying from thirty-five to forty pounds.

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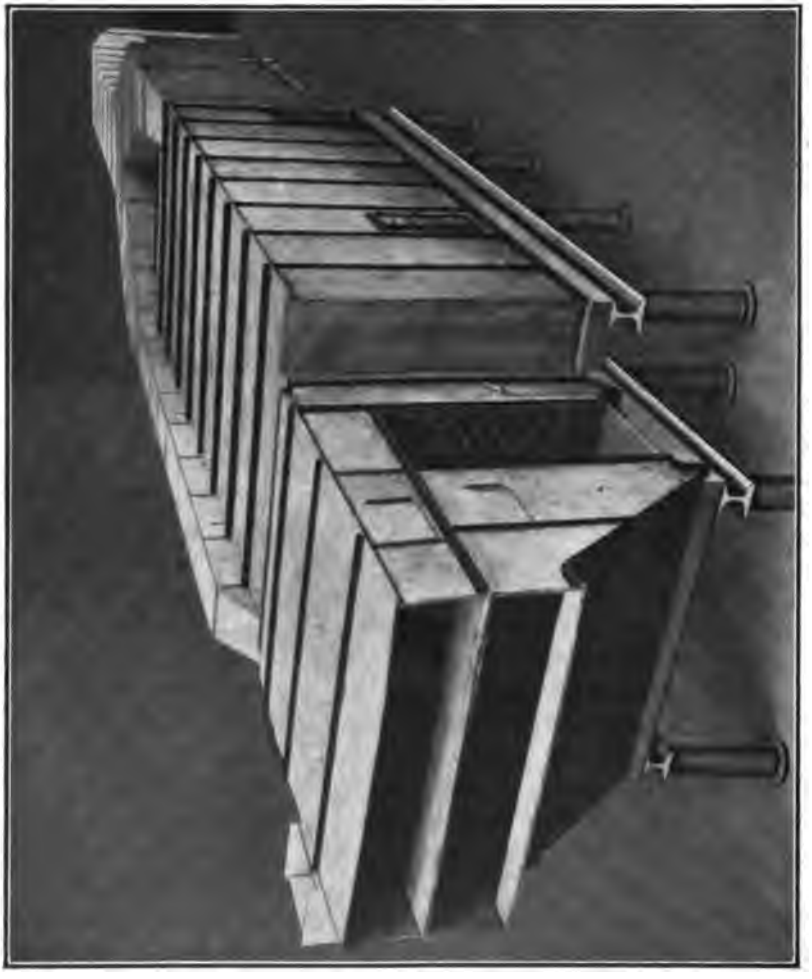

FIG. 10.—CARRIER DEHUMIDIFIERS AND INTERCHANGER.

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The dew point, or the temperature at which the air leaves the final dehumidifier, is automatically controlled by by-passing a portion of the water around the Baudelot coils and mixing it with water which has been cooled, thus procuring the proper temperature for the work required.

Fig. 11 and Fig. 12 show the splendid results obtained by this means of control. In blast furnace work a great saving of refrigeration is effected where the moisture can be removed after the air has been compressed. The dew point for a given weight of water vapor in a given space is dependent upon the vapor pressure, and not upon the air pressure. By compressing the mixture of air and water vapor, the dew point required for the same final relative weights of vapor and air will be raised. To illustrate: If it is desired to reduce the water vapor to two grains per cubic foot of free air, and the dehumidifying is done at atmospheric pressure, it is necessary to reduce the air to a temperature of approximately 30 degrees Fahr. If, however, the air is compressed to double the absolute pressure, it will occupy only one half the space, and it will be necessary to cool the air only to a dew point of approximately 50 degrees Fahr. in order to reduce the vapor content to the same weight per pound of air.

The total work required after compression is much greater, as the heat of compressing the air must be removed in addition to that necessary to produce the required condensation. The elevation of the temperature plane not only allows of a high suction pressure at the ammonia compressor, with the resultant increased economy, but it also makes it possible to do a very large portion of the work by water from any convenient source, such as rivers, lakes or wells. The colder the water available, the less refrigeration is required. One reason this method has not been more popular until recently is that any variation in the air pressure causes a variation in the amount of moisture carried to the furnace.

There are two systems of dehumidifying under pressure which have been designed for blast furnace application, only one of which, I believe, has been put in operation. In both of these systems the work is done with sprays. In one, invented by David Baker, a constant air pressure is maintained in the dehumidifier by a regulating valve placed in the blast pipe leading to the furnace, and a constant dew point is regulated by a thermostat. The other system, invented by John B. Miles, provides for varying automatically the dew point temperature of the air leaving the dehumidifier, in relation to the

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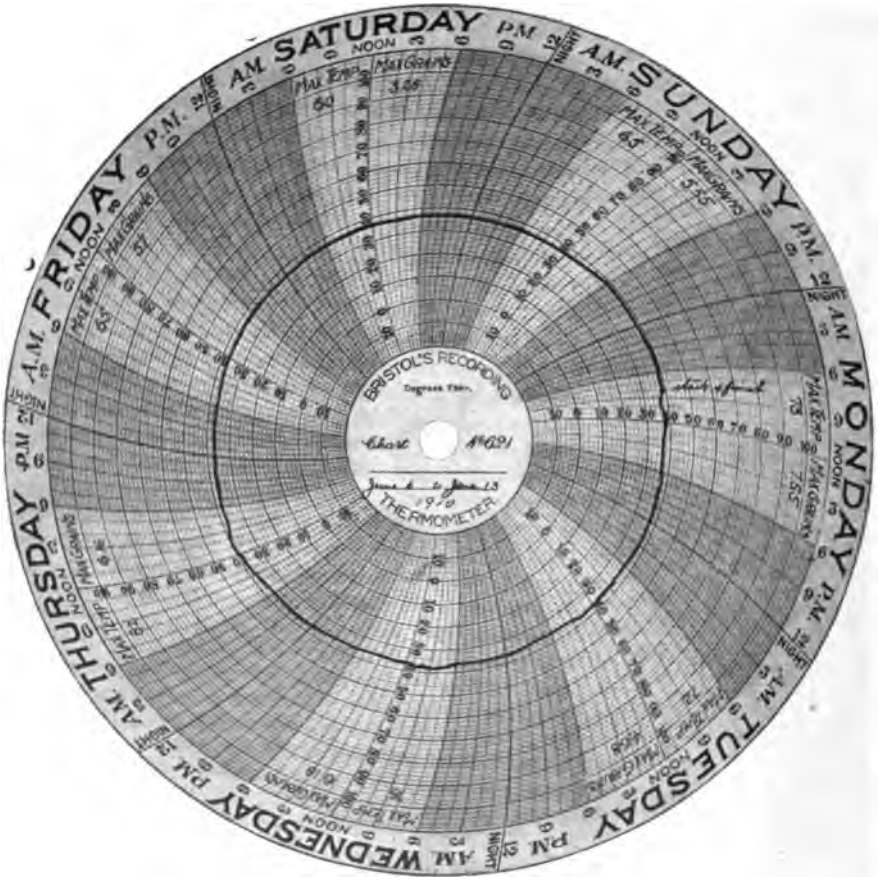

FIG. 11.—CHART SHOWING EFFECT OF AUTOMATIC DEW POINT REGULATION.

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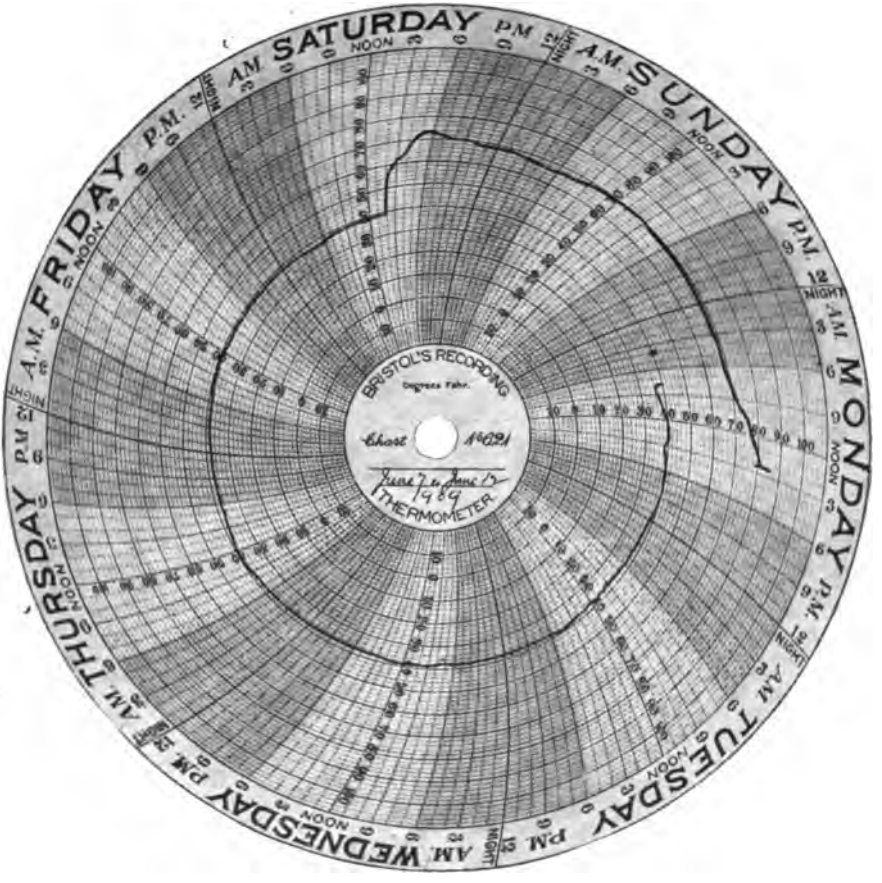

FIG. 12.—CHART SHOWING EFFECT OF AUTOMATIC DEW POINT REGULATION.

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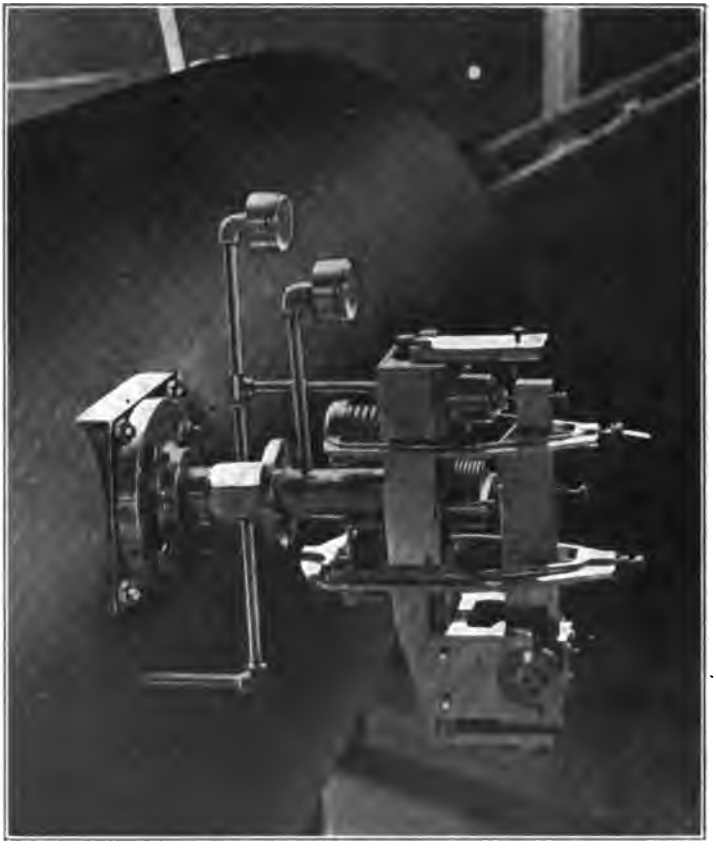

FIG. 13.—L. & M. REGULATOR FOR VARYING DEW POINT TEMPERATURE TO MAINTAIN CONSTANT ABSOLUTE HUMIDITIES WITH VARYING AIR PRESSURES.

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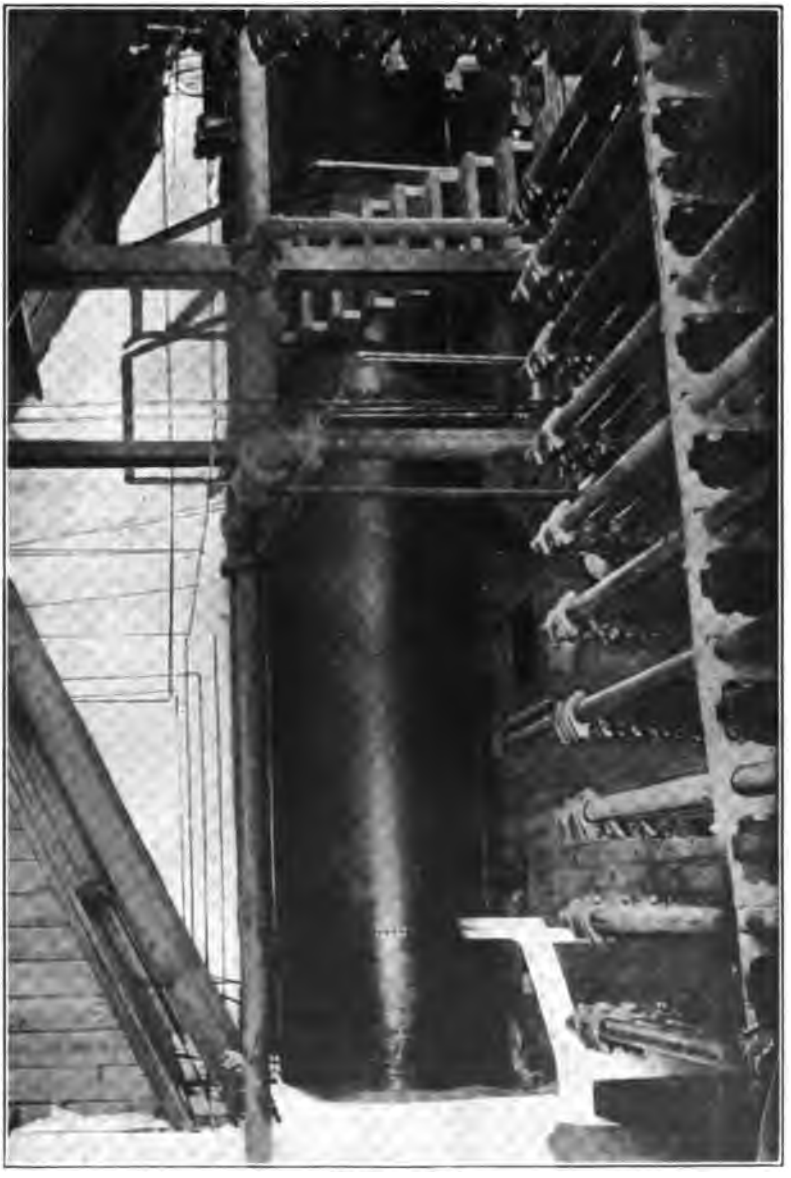

FIG. 14—HORIZONTAL DIRECT SPRAY DEHUMIDIFIERS. PLANT OF NORTHERN IRON CO., STANDISH, N. Y.

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FIG. 15 SIDE VIEW OF HORIZONTAL DEHUMIDIFIERS. PLANT OF NORTHERN IRON CO., STANDISH, N. Y.

of the remaining work can be done without costing more than refrigerating apparatus displaced, and with no operating expense.

The third stage, using water or brine which is artificially cooled, reduces the air to the final dew point required. The dew point, however, is not so low as in the case with an atmospheric pressure.

Fig. 14 and Fig. 15 show the dry blast plant of the Northern Iron Company's furnaces at Standish, N. Y. The dehumidifiers of this plant are the horizontal cylinders partly shown in the illustration. The work is done after the air has been compressed to 10 pounds gauge pressure, making it necessary to cool the air only to a dew point of 41 degrees Fahr., while, if done before compression,

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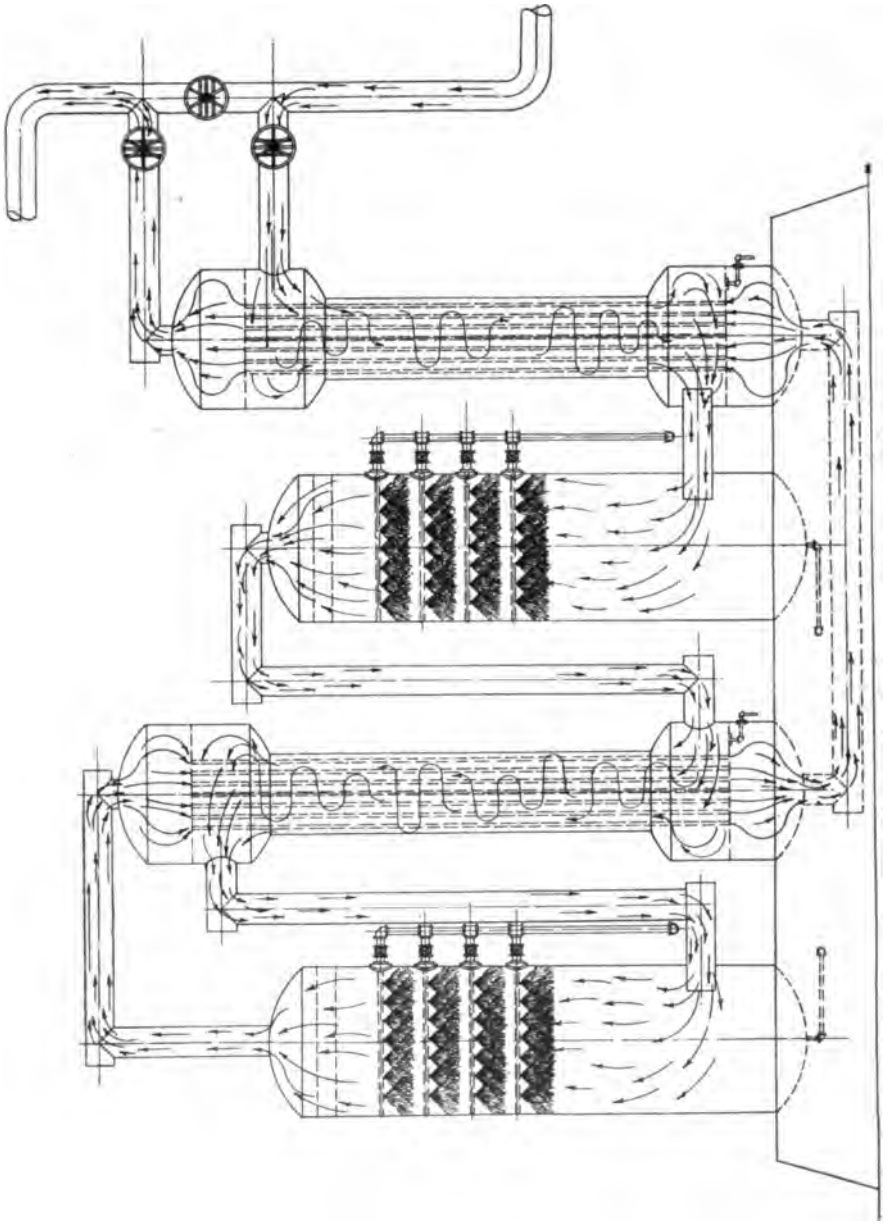

FIG. 16.—SPRAY DEHUMIDIFIER WITH INTERCHANGER FOR USE ON COMPRESSION SIDE OF BLOWING ENGINE.

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variations in the air pressure to procure a constant relation of the weight of water vapor and air.

The relation between the air pressure and the dew point required is a variable, and an automatic regulator invented by E. T. Murphy and the author, shown in Fig. 13, is used to maintain this relation.

By interposing an interchanger between the first stage using natural water and the last stage using refrigeration. 30 to 35 per cent.

FIG. 15.—SIDE VIEW OF HORIZONTAL DEHUMIDIFIERS. PLANT OF NORTHERN IRON CO., STANDISH, N. Y.

of the remaining work can be done without costing more than refrigerating apparatus displaced, and with no operating expense.

The third stage, using water or brine which is artificially cooled, reduces the air to the final dew point required. The dew point, however, is not so low as is the case with an atmospheric pressure.

Fig. 14 and Fig. 15 show the dry blast plant of the Northern Iron Company's furnaces at Standish, N. Y. The dehumidifiers of this plant are the horizontal cylinders partly shown in the illustration. The work is done after the air has been compressed to 10 pounds gauge pressure, making it necessary to cool the air only to a dew point of 41 degrees Fahr., while, if done before compression,

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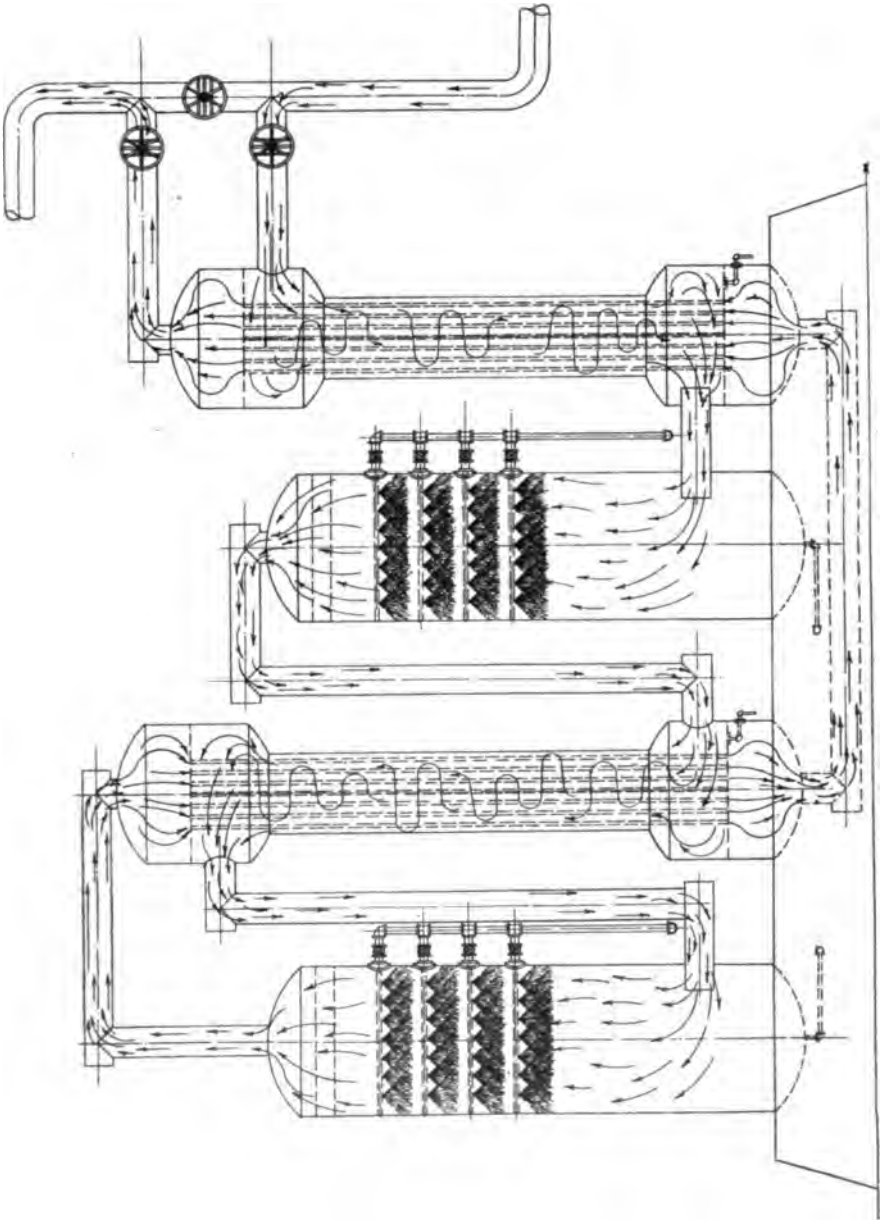

FIG. 16.—SPRAY DEHUMIDIFIER WITH INTERCHANGER FOR USE ON COMPRESSION SIDE OF BLOWING ENGINE.

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to produce the same results, one and three-fourths grains per cubic foot, would require a dew point temperature of 28 degrees Fahr.

The first stage of this apparatus makes use of water procured from a nearby mountain stream, and the second stage uses artificially cooled water.

With compressed air the efficiency of the interchanger is greatly increased, due to a greater density. With an interchanger having the same first cost as the refrigeration which it displaces, the refrigeration required is reduced to 30 to 40 per cent.

Fig. 16 shows a dry blast plant designed for doing the work after compression, using vertical tower and interchanger.

The principal advantages of dehumidifying for blast furnaces on the compression side of the blowing engine are: First, the large amount of work which can be done by water from natural sources; second, the high efficiency of an interchanger; third, the high ammonia suction pressure; fourth, a very low first cost; fifth, small space required, and sixth, low cost of maintenance.

DISCUSSION.

President Shipley.—This is a matter which we are all interested in. It is one which means considerable to the ice machine manufacturer. The engineering fraternity in general are interested in this matter. You know that the development of the dehumidifying apparatus is cutting us off the slate right along. They are getting nearer and nearer to leaving out the refrigerating machine altogether. We ought to be interested to see how they are doing it. You will note that this paper states that by taking the moisture out of the air after it is compressed, they cut us out from 30% to 40%. There is some virtue even in that fact from our standpoint, for the reason that if we can bring the cost of installation and operation down, there will be more of these plants used, so while our apparatus may be cut in half, we will get many more plants; hence we will get there just the same, but we ought to know how the saving is brought about. Any questions?

Charles H. Herter.—There are a few questions I would like to ask. Under what pressure is the water passing through the nozzles?

J. I. Lyle.—That depends a great deal upon the design of your nozzle. Pressure can be used anywhere from 15 to 45 pounds and get good spraying. Usually pressures of about 25 pounds are employed.

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Charles H. Herter.—Are the nozzles you use of your own manufacture?

J. I. Lyle.—Yes. The nozzle is a patented device. Professor Barnard, of Cornell University, is the patentee of it.

Charles H. Herter.—How many cubic feet of water are sprayed from a nozzle per minute?

J. I. Lyle.—That depends on the proportion of the number of nozzles to the amount of water you want for the work to be done, and that, in turn, depends on the range in temperature through which you want it to carry the air for the condensation. We make nozzles for handling from a pound a minute up to 500 gallons a minute.

N. H. Hiller.—I would like to ask, with your interchangers, have you found very much difficulty from corrosion due to precipitation of moisture? These are made, as I understand, of comparatively thin metal, to get good conductivity; as you take your air from the higher temperature to the lower, it must deposit some moisture. Have you had any trouble from corrosion and how long have you had those interchangers in operation?

J. I. Lyle.—I think it is three years ago that they were put in. They have been through three summers; they have been made of thin metal, as you state; they have been working at atmospheric pressure, and we have made them galvanized both inside and out, allowing no exposed iron surface. We have had no trouble from corrosion so far.

L. Howard Jenks.—In applying the system to cooling perishable products, as in cold storage work, how many grains of moisture per cubic foot do you carry over finally into the cold storage room, and what means do you take to prevent the carrying of even a very small amount into storage rooms?

J. I. Lyle.—We haven't done any cold storage work. That would not answer that question, probably, but the reason we haven't done any is because we have been sufficiently busy trying to take care of the higher temperature work about as fast as we could. We have found so many applications for this type of apparatus which has not been touched by the refrigerating manufacturer that it has kept us busy. I will say that this last year we had something like forty sales of dehumidifying apparatus in plants where the people would not consider the ordinary refrigerating equipment; so, instead of hurting Mr. Shipley, as he rather suggested, we have been helping him. To come back to your final point—the amount of entrainment depends a great deal on the saturated temperature through which

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the air falls in the last stage; if you were cooling it in the last stage from a saturated temperature of 75 degrees down to 31, you would carry several times the amount of moisture that you would if you were only cooling it in the last stage, from 32 to 30, but ordinarily that will not amount to one-tenth of a grain per cubic foot of air—that will be excessive.

Peter Neff.—What rise in temperature will take care of that?

J. I. Lyle.—About one degree. I have never made a test, and so far as I know, Mr. Carrier has never made a test that showed as much as one degree rise necessary to dissipate the moisture.

F. L. Fairbanks.—We put in a large system on practically that basis. We cooled the air through a range of only five degrees, although we handled, of course, very large quantities of air. We had, as I remember it, something like a five-foot disc fan that was operating at upwards of 500 revolutions a minute. We operated on the tower principle, with a fine spray, the air being in direct contact with the refrigerated brine at a temperature of 12 below zero. We got a very high efficiency. We cooled the air easily within two degrees of the temperature of the brine, and got what we thought was a very clear, clean and dry condition. We found, however, that there was a fraction of one per cent. of the chloride of calcium or chloride of sodium carried over, and while that fraction of one per cent. was apparently not detrimental or of any great moment for a week or two, we found that continuously circulating that air finally built up a scale of the chloride of calcium or chloride of sodium on the goods, which made it absolutely prohibitive. There was nothing we could do to bring the amount down to a point where it would not build up, operating, as we were, on cold storage, 24 hours a day and 365 days a year, with goods in storage anywhere from a month to six or eight months.

While we had an excellent opportunity for employing this system, inasmuch as we took the entire brine return from our warehouse system, where the brine, something like two to three million gallons in 24 hours, had done its work while circulating through the coils in the various rooms, the fact that the material, whether calcium or sodium, gradually accumulated on the goods, made the use of the system prohibitive. We brought this 14-inch return down from the top of the building through what was formerly a shaft, and by simply putting a baffle plate at the top of that air shaft we converted the return brine in the drop to the return tank into a finely divided spray. We introduced the air at the

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bottom, driving it up the tower, giving a counter current effect. We then passed it through baffles, and even through consecutive layers of burlap, which picked up a very large amount of brine after it passed through the baffles. We circulated the air into the rooms and the fan took it from the rooms, making practically a closed circuit. While, as I say, we got very high efficiency, so far as the effect of the brine on the air was concerned, there was no possible way of eliminating the entrainment.

We also found that when we got down to a very fine spray we carried over more brine than we did with the coarser spray. We assumed that the system would be more efficient with a finely divided spray, but we did not find that a fact. The particles were so fine that the air evidently did not come in contact with them readily. They did not hold in the air current, but were blown against the side of the tower, so that we found that the most efficient tower was one in which the size of the brine drops was from a sixteenth to an eighth of an inch in diameter, in which condition the air picked up a minimum amount of the material, whereas with a very fine spray, and we used sprays which were so fine that it was almost like a cloud, we found the high velocity air carried the brine through the baffle plates much more readily. We finally had to discontinue the use of the system entirely on that account, but it made a very efficient system at a very low cost; that is, we could cool a very large number of rooms with no coil system whatever. Practically, all it required was dropping the brine down through the tower with a fan sufficient to circulate the air; so the first cost of the system was practically nothing.

Morgan B. Smith.—I would like to ask Mr. Fairbanks if he passed the air over lime or some other dehumidifying material?

F. L. Fairbanks.—We did try chloride of calcium racks, but the volume was so large that it would have required a houseful to have any effect. The air was traveling at such velocity that it did not have time enough, in going over the chloride of calcium, to deposit any large proportion of its moisture. We also tried unslacked lime; we didn't ever expect to make that a success, but we wanted to see what we could do, and, besides, we needed some lime in our building operations, but the re-evaporating effect brought the water over into the room and deposited it in the form of frost, and ice built up very quickly.

I may say that with the circulating system with the chloride of calcium, we got almost no frost in the room, as the calcium would seem to pick up the moisture and carry it back into the tank solution

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instead of depositing it in the form of frost in the room. Our system is so large and we have such a large constant loss which we have to make that up every day that we overcame our difficulties by making our replenishing brine a little stronger than would otherwise be necessary. We had no trouble in maintaining a constant strength as well as constant quantity of brine in the system.

J. I. Lyle.—I want to say that Mr. Fairbanks' idea that the finer the spray the harder it is to remove is not correct; that is, if he has a proper design of eliminator. The moisture that is hard to remove, the entrainment which is carried over, contains a very small percentage of the calcium of sodium brine, if the eliminators are properly constructed; it is the moisture being condensed out of the atmosphere in very minute particles, a spray much finer than it is practicable for you to create with any form of nozzle.

We have experimented with all sizes of nozzles, producing all sizes of sprays, from one-inch hole down to the smallest size, and there is a point beyond which it does not pay to go in the atomization of water, because the transfer of heat will be completed without getting it any smaller. The entrainment is a question of the condensation from the atmosphere itself. About three or four years ago we had up with the United States Steel Corporation the subject of dehumidifying for some of their blast furnaces. They thought at that time they were going to do wonders; and we did too, and we spent a lot of money to convince them that we could do the work in this manner. We ran a plant for some four weeks, using calcium brine. They had analyses made of the air for entrainment, and we also put in excelsior bagging and lots of other things to catch it. We did get, as I said in the paper, some calcium carried over, but it was a very small percentage as compared with the amount of water carried over, which was due to the condensation. It was not taken out; it was apparently condensed, brought to a fog state and then afterwards re-evaporated. I don't believe that you can use calcium brine in connection with any food products or where the air has to be breathed. I am rather surprised at what Mr. Fairbanks has said about sodium brine, because our experience so far has not led us to believe that was true. It seemed to us that if there was any of the salt carried over, it was so minute that we have not been able to find it. We have done some work with sodium brine for quite a length of time, but not in connection with low temperature work.

F. L. Fairbanks.—Why should not the same percentage of sodium brine be carried over as of calcium?

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J. I. Lyle.—I don't know, only we never get an odor with sodium brine and we have never used calcium brine that we didn't get an odor. One thing that first brought to our attention that we were not getting complete elimination was the odor of calcium brine. We discarded our calcium brine and ordered some special calcium from a concern as good as any in the country, and still got the odor from the brine.

F. L. Fairbanks.—It is assumable that whatever of the substance is carried over, is carried over in solution. Well, then, assuming that the specific gravity of the liquids is not greatly different, with the same atomization, there isn't any reason why sodium chloride should not carry over as readily as calcium chloride at those temperatures, is there?

J. I. Lyle.—Absolutely not, but that is the very point. I think that some of the manufacturers claim to have 99.97% pure calcium, and calcium has no odor, has it?

F. L. Fairbanks.—We don't know that it has any particular odor, that is, not any detrimental odor.

J. I. Lyle.—Was it calcium or something in the calcium that we got the odor from? We invariably got it. Or was it a compound, resulting from a mixture of something in the air and the calcium?

F. L. Fairbanks.—We got odors which we described as probably chloride of calcium, but we found that it came from other materials. We chased an odor six months and finally found that it was in the core of one of our elevator cables; the mineral oil that we used to prevent the cable from rusting had created the odor. The point I wish to make is that calcium does carry over, even if only a tenth of one per cent. If you are operating 24 hours a day and 365 days a year and pumping 3 to 4,000,000 gallons of brine, as we are, it does deposit on the goods, and it is a question of how much your customer will allow you to deposit before you have to stop. We thought it advisable to stop before we got a bad reputation.

N. H. Hiller.—Oftentimes the trouble with calcium chloride can be traced to the water. Was the water used distilled?

J. I. Lyle.—In this case we were operating an ice plant and used distilled water when we got the second lot of calcium to mix, but we still got the odor.

Morgan B. Smith.—I believe Mr. Fairbanks brought up the question, Why shouldn't sodium chloride carry over as well as magnesium and calcium chloride? Every substance has a tendency to go into the form of vapor, and it is a well-known fact that calcium chlo-

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ride possesses that property in a much higher degree than sodium chloride, and magnesium in a higher degree than calcium chloride. For that very reason the amount of calcium or magnesium chloride which would be kept in the air in a state of true vapor would be much greater in all cases than with sodium chloride.

George A. Horne.—I would like to ask Mr. Smith if there is anything in the calcium chloride other than the chloride itself which might give rise to such an odor as Mr. Lyle refers to?

Morgan B. Smith.—It is getting into the calcium trade a little bit to differentiate between the so-called natural chloride and what you might call the by-product of chlorides. If the chloride purchased was a chloride resulting from the manufacture of salt, I would say that the odor might easily be due to bromide or one of the similar by-product constituents.

George A. Horne.—It seems to me that if there is any chemical carried over in entrainment by mechanical means it could be easily determined whether it is sodium or some other chloride.

Morgan B. Smith.—Chemical tests would identify the chloride. I should say that the mechanical entrainment might be easily removed, possibly by a suitable system of baffles.

George A. Horne.—From a warehouseman's standpoint, it would be interesting to know whether or not the volatile matter cannot be eliminated, too, so that we would have no bad effect on our goods.

Morgan B. Smith.—I do not know of any effective means as yet developed.

Charles H. Herter.—I want to ask one more question. Is this feature of cooling the air after compression to reduce the work by one-half covered by a patent? It was not spoken of until six or seven years ago and was then considered quite a novelty and a great saving.

J. I. Lyle.—There are two or three patents. I believe one of John B. Miles covers the varying of the dew point, or saturation temperature, with a varying air pressure, so as to maintain a constant weight of water vapor per pound of air. Another patent by David Baker covers the idea of dehumidifying under a constant air pressure, but there is no patent covering the general subject of dehumidifying after compression, and nothing to prevent anybody from doing it.

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No. 106

CORROSION IN REFRIGERATING SYSTEMS

A SUMMARY OF THE CHARACTERISTICS OF BRINE WITH REGARD TO ITS RELATION TO THE PROBLEM OF CORROSION, VIEWED FROM A LABORATORY STANDPOINT, AND FROM CONDITIONS NOTED IN PRACTICE.

By Morgan B. Smith, Detroit, Mich.

(Associate Member of the Society)

In this paper I shall attempt to comply with several requests that I give to this Society a summary of the results of my experience in the study of the corrosion problem in refrigerating systems, with regard to the relation which the circulating brine bears to the conditions generally pertinent to the refrigerating apparatus, and other associated apparatus. To do this subject full justice would require a lengthy treatise, for which reason I must limit myself to general outlines of the subject, going into detail only where clearness demands such treatment of the subject.

Inasmuch as the study of corrosion involves experiments and laboratory verification of the theories involved from the conditions noted in practice, I shall give, first of all, a short summary of the conditions which we now know to be conducive to corrosion, and which are almost invariably present, singly or collectively, when corrosion is manifest.

Before giving this summary I may state that the manufacturers of chlorides for refrigerating purposes have been forced to put a better quality of chlorides on the market—chlorides of such a nature as would not tend to accelerate corrosion. The result of this has been the appearance on the market of neutral or slightly basic (alkaline) chlorides. These chlorides ought never to become acidic in nature, due to decomposition of the constituent chlorides. I may say in this connection that it is a fairly well established fact that ferric chloride will decompose under certain, not as yet well defined, conditions, with formation of free hydrochloric acid. I believe the makers have now overcome this latter difficulty by destroying all ferric chloride in the process of manufacture.

In spite of the fact that the chlorides have been made as near corrosion-proof as such good electrolytes can be made, corrosion

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still went on, less markedly than before, but still at times much in evidence. This made it manifest that other conditions were present which had to be corrected before corrosion could be minimized, if not wholly done away with. It is this latter phase of the problem which has taken years of study and observation in practice which have resulted in the isolation of the following conditions now known to be singly or collectively conducive to corrosion. These, briefly, are:

First. Combinations of unlike metals with the electrolytic brine.

Second. Combinations of the same or like metals in brine, but of varying degrees of purity, and segregation of impurities.

Third. Metal in a state of strain, especially torsional stress.

Fourth. Cutting effect of heavy brines when forced at high velocity through short-turn bends, or through piping of too small diameter relative to the volume of brine carried.

Fifth. The presence of air (oxygen) in the piping, or other apparatus, or in solution in the brine itself.

Sixth. Faulty construction of the brine-carrying apparatus so that the brine, originally free from air or relatively so, soon becomes saturated with air (oxygen) and, in consequence, highly conducive to corrosion.

Seventh. Comparatively high brine temperatures which are relatively conducive to corrosion, compared with lower temperatures.

Eighth. The action of electric currents through refrigerating systems, especially the brine-carrying parts.

Ninth. Actual contact with electric current-carrying circuits, due to faulty installation of wiring, conduits, etc.

Tenth. Leakage of electric current from poorly installed metallic conduits, which are neither grounded nor insulated from their supports.

Eleventh. Poor quality of metal used in the brine-carrying parts of the system, especially in the case of cast iron used in headers, pumps, etc.

Twelfth. So-called protective coatings, which in many cases actually accelerate corrosion, rather than inhibit it.

Thirteenth. Galvanized iron of poor quality, which resists corrosion very well for a short time—until the zinc has been dissolved away sufficiently from the iron to extend beyond the limited zone of protection from corrosion. Only the very best grade of galvanized iron should be used, since it is well to bear in mind the evidence that the iron used for galvanized iron is seldom of good quality; and so,

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once the zinc has dissolved so as no longer to protect the iron, the iron itself will almost invariably be attacked very vigorously.

In order to show the behavior of metals in brine, many laboratory tests have been made with the conditions maintained similar to those of practice, excepting only temperatures. Inasmuch as the temperatures were in all cases high, when compared with those of practice, the conditions were probably more severe. Some accelerated tests were made, but consistent results were not obtained, the conclusion reached being that these tests should be carried out under normal conditions, and should be of sufficient duration to demonstrate the general tendency of the reactions between brine and metal. For this reason tests were conducted covering not less than 100 days—in some cases a year or more—to allow full time for the reactions. The metals were only seven-eighths immersed in brine, as this simulates a condition very general in practice. The test pieces were 3½ inches by 1 inch by ¼ inch in size. The brine was renewed every seven days. The change in weight of the metals was noted at frequent intervals, and calculated in terms of change in weight per unit surface exposed to the action of the brine. The results of such tests on single metals are shown in Plate 1, the curves representing the general or average behavior of the respective metals in brine under the conditions noted.

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TABLE 1.

SINGLE METALS IN BRINE.

Surface Losses in Terms of Miligrams per Square Meter Surface.

Time Days.	Aluminum.	Bronze.	Brass.	Copper.	Solder.	Iron, Good.	Iron, Bad.	Tin.	Lead.	Galvanized Iron.
5	....	....	....	....	....	....	....	....	....	−350
10	+115	0	−20	−40	−70	−90	−130	−70	−70	800
20	+190	0	50	80	130	170	230	260	260	900
30	+210	0	70	90	180	210	300	340	340	950
40	+230	−20	80	110	....	....	390	....	....	980
50	+240	....	90	160	230	280	480	450	470	990
60	+250	....	120	....	....	....	....	....	....	....
70	....	30	150	220	300	330	710	540	630	....
80	....	....	160	240	....	....	....	....	....	....
90	+275	40	170	260	340	390	970	650	850	....
100	....	....	180	280	370	....	1240	720	1030	....
110	....	55	....	....	....	460	....	....	1210	....
120	....	60	230	350	410	....	....	820	....	....
130	....	....	....	....	....	500	....	....	....	....
140	....	70	330	440	550	....	....	970	....	....
150	+290	....	....	....	....	630	....	....	....	....
160	+290	90	470	600	650	....	....	1090	....	....
170	+290	100	542	710	740	830	....	....	....	....
180	....	103	620	820	830	950	....	....	....	....

The peculiar behavior of aluminum is characteristic of this metal in a number of solutions, among which are the solutions of sodium-bicarbonate and of ammonium-bicarbonate and in certain organic solutions, and is apparently due to the accumulation of a strongly adherent coating of oxide. Aluminum actually gained in weight on this account.

The alloys seem more resistant to corrosion than do the metals of which the alloy is composed. This is seen in the behavior of bronze and of solder.

The comparative behavior of iron of good and of bad quality is so evident as to merely require mentioning.

The behavior of galvanized iron is very characteristic. The great loss during the first ten days' immersion is due to loss of zinc, during which period almost no iron went into solution. At the end of this period there was not sufficient zinc remaining to further protect the iron, with the result that iron began to dissolve along with the remaining zinc. The reaction then gradually assumed the same characteristics shown by the iron of good quality. It is evident that the galvanized iron used in these tests had very good iron as the base.

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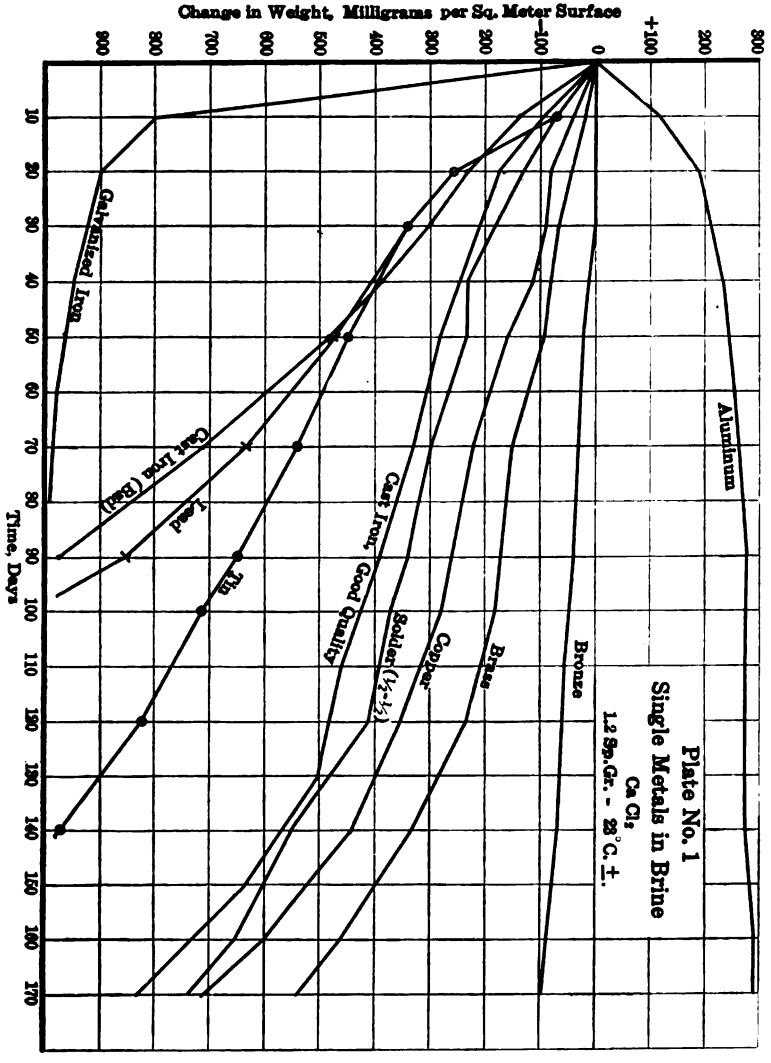

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It must not be supposed that the figures shown on the chart are absolute quantitative results. On the contrary, I must emphasize the fact that they are merely comparative, under the conditions maintained in the tests. Different conditions might readily alter the comparative results. On the whole, however, I believe they are fairly representative of the behavior to be expected of the respective metals in brines of any description. This applies also to the charts that follow.

The behavior of single metals suggested the combination of dissimilar metals, especially such combinations as were often met with in practice. Plate 2 shows the general results of tests carried out with single metals, as described above. The metals were merely held in contact by pressure from rubber bands applied at the two ends and center of test pieces. The combinations of similar metals—namely, copper-copper and iron-iron—show relatively much less change in weight than do the combinations of dissimilar metals—namely, copper-iron and brass-iron. This is due to the so-called galvanic or local cell action of unlike metals in an electrolyte. The effect of raising the temperature of the electrolyte (brine) is clearly shown in the broken-line curves, which indicate a very marked acceleration in the cell action of the respective couples, copper-iron and brass-iron.

The behavior of aluminum when immersed in brine singly made it desirable to note its action when combined with unlike metals and immersed in brine. Accordingly, the following couples were tried out, aluminum-iron and aluminum-copper, the losses of each metal being noted, and also the combined loss of the two metals. This total loss, as well as the individual losses, are shown on Plate 3. Aluminum seemed to exert no such effect as was noted in the tests on single metals, Plate I. The couple aluminum-copper, as was expected, showed greater losses than the aluminum-iron couple, the reaction being at the expense of the aluminum. The aluminum curve shown is based on the data of Plate 1, and is shown merely for comparison.

In many conditions of practice soldered joints between dissimilar metals are a necessity, and for this reason it was considered advisable to make tests on metals joined in this manner. Accordingly, couples of brass-brass, copper-copper, copper-brass, iron-iron, brass-iron and copper-iron were made with solder as the joining medium, Plate 4. These were then tested in the same manner as the tests shown in Plates 1, 2 and 3.

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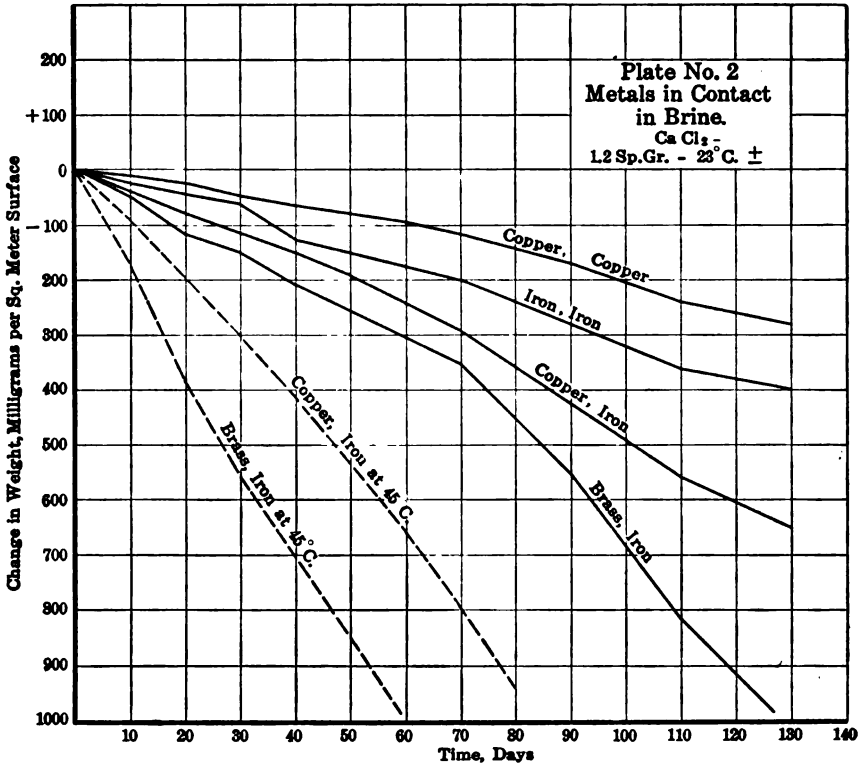

TABLE 2.

DISSIMILAR METALS IN CONTACT IN BRINE.

Surface Losses in Terms of Miligrams per Square Meter.

Temperature, 23 Degrees Centigrade.

Time, Days.	Cu.-Cu.	Fe.-Fe.	Cu.-Fe.	Brass-Fe.	Cu-Fe. 45° C.	Brass-Fe. 45° C.
10	−15	−25	−30	−40	90	155
20	25	40	50	82	192	380
30	50	62	80	118	300	550
40	65	...	150	150	412	700
50	...	125	190	210	532	841
60	95	...	...	...	650	1000
70	115	200	288	350	790	1150
80	...	...	...	...	940	...
90	170	280	422	550	1105	...
100	...	...	...	....	1280	...
110	240	360	560	810	...	...
130	280	400	650	1020	...	...

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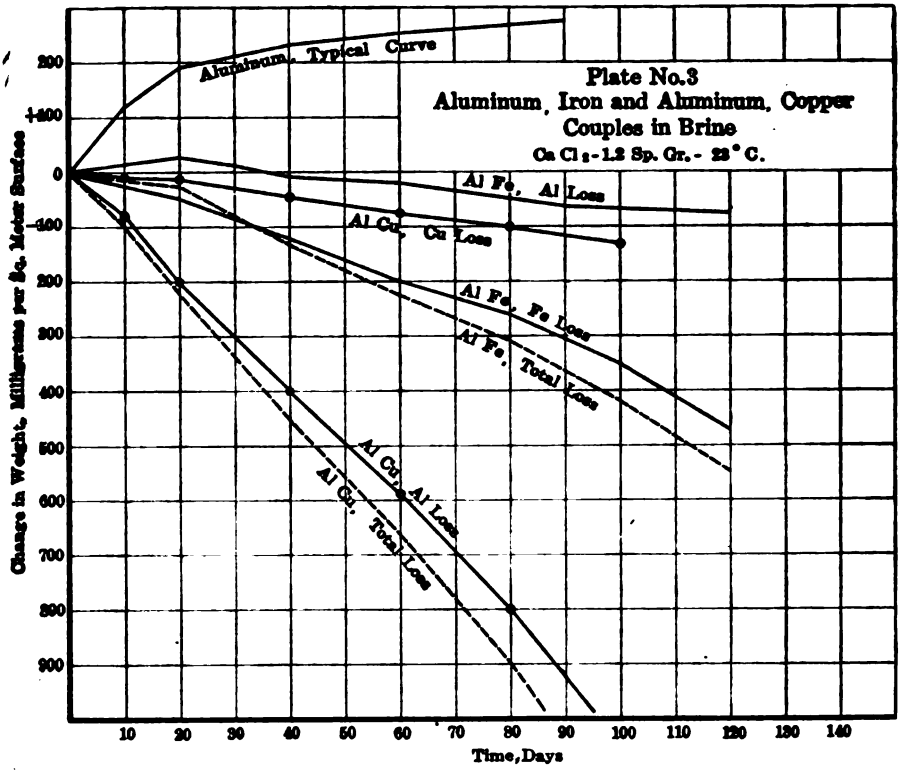

TABLE 3.

ALUMINUM IN CONTACT WITH OTHER METALS IN BRINE.
Change in Weight—Miligrams per Square Meter.

Couples.	Al.-Fe.			Al.-Cu.		
Time, Days.	Al.	Fe.	Total.	Al.	Cu.	Total.
10	+10	−28	−18	−80	−10	−90
20	+25	50	25	200	16	216
30	−10	85	75	...	...	...
40	10	120	130	400	50	450
60	21	200	221	587	72	659
80	43	260	303	796	100	896
100	65	350	410	1050	130	1180
120	73	470	543	....	...	....

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The solder seemed to exert an effect similar to that shown by the zinc of galvanized iron, inasmuch as the solder went into solution in each case. The reaction on the metals other than solder was slight, compared with the effect on the solder. The combinations of dissimilar metals again, as in tests of Plate 2, show much greater losses than do those of similar metals. These tests were of nine months' duration, only one hundred and seventy days' tests being shown on this chart, since the general results are well defined during this period. I may say that the brass-iron soldered couple continued to show less loss than did the copper-iron soldered couple in these tests.

The gain in weight shown by the brass-iron, the copper-brass and the copper-iron couples was probably due to an accumulation of

TABLE 4.

DISSIMILAR METALS IN SOLDERED CONTACT.

Change in Weight—Miligrams per Square Meter.

Time, Days.	Brass-Brass.	Cu.-Cu.	Cu.-Brass.	Fe.-Fe.	Brass-Fe.	Cu.-Fe.
-5	...	-70	+60	-50	+110	+90
10	-50	88	-30	70	+30	-50
20	70	115	140	105	-50	205
30	80	130	160	150	130	270
40	100	150	180	192	170	350
60	110	160	220	240	250	450
80	150	180	250	290	340	553
100	170	208	280	372	470	735
120	190	210	330	483	*620	*980
140	210	230	350	630	†900	†1220
160	250	260	400	820	‡1210	...
180	270	280	430	1050	...	...

* 110 days; † 120 days; ‡ 125 days.

weakly adherent oxides, possibly due to air (oxygen) in brine, which was soon used up, after which oxidation was not manifest even on repeated renewal of the brine.

The net result of all these tests was to prove that even under the best conditions some corrosion may be expected when single metals, or combinations of dissimilar metals, are immersed in an electrotype, such as brine.

Some of these tests were carried out with the metals completely immersed in the brine, the fact being brought out that the losses, when the metals are only partially immersed, are roughly ten times as great per unit of time as when the metals are completely immersed.

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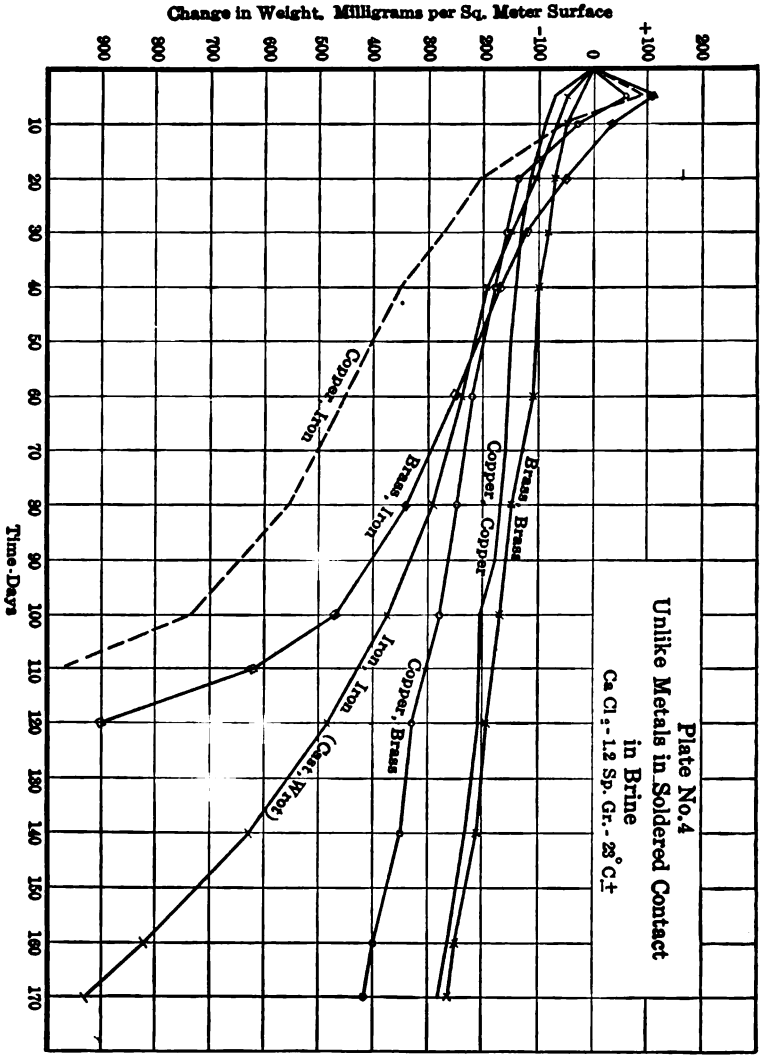
Plate No.4
Unlike Metals in Soldered Contact
in Brine
Ca Cl2 - 1.2 Sp. Gr. - 28° C.
Change in Weight. Milligrams per Sq. Meter Surface
200
+100
0
-100
200
300
400
500
600
700
800
900
Time-Days
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Brass, Brass
Copper, Copper
Copper, Iron
Brass, Iron
Iron, Iron
Copper, Brass
(Cast, Wrot)

This only bears out in a very striking manner the facts noted in practice, namely, that air (oxygen) must be kept out of the refrigerating system just so far as is possible. Brine-containing apparatus and piping must be kept completely filled with brine, so that air cannot accumulate in high parts of the apparatus. Wherever air does accumulate, corrosion will manifest itself sooner or later. If all such air is removed and not allowed to accumulate again, one of the most active agents conducive to corrosion is eliminated.

In order that the effect of electric currents, when sent through a system composed of two dissimilar metals in brine, might be noted, tests were made using electric currents of low potential, and of almost no amperage. It was not necessary to use large currents, since the effects of such currents were known. The effects of very small currents were in proportion to their magnitude, as was expected, the main point brought out being that currents showing a potential as low as one milli-volt actually hastened corrosion.

The fact was driven home that engineers in charge of our refrigerating plants, in their tests for leakage of current, were missing the very currents which in many instances were causing remarkable acceleration of corrosion, if not actually starting the reaction. The second fact driven home was that the tests made for stray electric currents must be made with instruments capable of detecting extremely small differences of potential. In this regard it must be admitted that considerable judgment must be used in these tests, carefully taking into account the distribution of these small differences of potential and the general environment, since in our great steel structures small differences of potential are nearly always to be found. It is at local points of increased potential that trouble is likely to appear, due to one or more of the following common sources:

First. Electric motors and generators not properly grounded.

Second. Electric motors direct connected on a common shaft with the centrifugal pump driving brine, and not insulated from the pump in any way.

Third. Suspension of electric lamp wiring, frequently for incandescent lighting, and often for arc lamps, directly from the brine lines or other brine-carrying apparatus.

Fourth. Electric wires carrying heavy currents in contact with the apparatus in such a way that the insulation is often completely rubbed through at the point of contact.

Fifth. Electric wiring, such as enunciator circuits, carrying

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only currents of momentary, small magnitude, but which, through frequent recurrence, often give rise to pronounced action.

Sixth. Poorly installed metal conduits from which current frequently finds its way into the brine lines, etc., as noted above.

Seventh. Sources of current entirely foreign to the refrigerating plant, as trolley circuits, arc light circuits, telephone circuits, etc.

It often happens that the source of stray electric current is far distant from the refrigerating system upon which it is exerting its destructive action. Only careful, persistent testing will locate the source of such currents.

Not long ago I was called upon to investigate a most pronounced case of corrosion in a water line leading into a factory building. This pipe had been repeatedly renewed, and was as often eaten out. It passed into the building below the drip from an acid bath used in a process employed in a room on the third floor. The ground below this drip was saturated with this acid (sulphuric) and acted merely to bathe the pipe with acid continually. Needless to say, this drip was removed and corrosion ceased after removing the acid-saturated earth from around the pipe line. I mention this only to point out the fact that it is the little things, often seemingly harmless, which exert powerful influences on the lasting properties of the metals in every day practice.

The data upon which the charts shown in the several plates are based are contained in the tables accompanying them.

In conclusion I can simply say that I hope that I have given to the members of this Society some data which may prove of value in the problem of the inhibition of corrosion in refrigerating systems. I assure you that I appreciate the opportunity afforded me to be of service to you.

DISCUSSION.

N. H. Hiller.—I would like to ask Mr. Smith, where he speaks in his paper of the cutting effect of heavy brines when forced at high velocity through short turn bends or through piping of too small diameter relative to the volume of brine carried, about what velocity he considers safe. Have you determined that?

Morgan B. Smith.—No, I have not. I meant that merely as an instance, or, rather, as a symptom, which we corrected and subsequently found no further trouble.

N. H. Hiller.—Of course, that is one of the things we try to

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do, to get high velocity in brine coolers without undue friction, and I would like to know what the limit is.

Morgan B. Smith.—I believe that trouble will not appear so much in a straight-away pipe as at the turns. It is where heavy brine takes a short turn that cutting is noted, whereas if you use a long turn this cutting effect seems to be minimized.

F. L. Fairbanks.—Mr. Hiller, we experimented a good deal on that, and found that 75 per cent. of our trouble was due to the fact that erosion kept the metal clean, and when we got our velocity down under three feet per second, the metal would scale over and all galvanic action would stop. That was not only true with elbows, but wherever there was a lip of any kind projecting into the brine, as in the case of one flange overlapping another. Anything which exposed the metal to the erosive action of brine would start that galvanic action. We have Venturi meters, in which the cast iron is an inch to an inch and a quarter thick, and within three or four years you could stick a jack knife right through them. There was apparently nothing left of the iron but stove polish; but we found that by removing all zinc from the systems, everywhere, and slowing velocities down to the point where the inside of the mains would scale over to form a protecting covering, we got entirely rid of the trouble. We found that by making a valve in which there was no zinc whatever, the life of the valve was indefinitely prolonged. We have had them in as long as seven or eight years. We also found that where we galvanized a pipe and the galvanizing wore or chafed off, the corrosion at that point proceeded very much faster, apparently, than on plain iron. I would like to ask Mr. Smith if he finds that compatible with his theory?

Morgan B. Smith.—That is practically what I stated with reference to galvanized iron.

F. L. Fairbanks.—For that reason we have eliminated galvanized coils, for wherever you have zinc in the system it forms a couple with something else, and though it may protect the individual piece of pipe galvanized, some other portion is going to go more rapidly.

Morgan B. Smith.—I do not believe that galvanized iron is a safe thing to use.

F. L. Fairbanks.—That is exactly what we have found. We have stopped it entirely, except on some of our outside brine lines.

Morgan B. Smith.—I know of some cases where re-galvanizing was done after the already galvanized metal parts were put together,

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making an apparatus far more resistant to corrosion than when it is not re-galvanized.

F. L. Fairbanks.—You agree, then, that a galvanized can placed in couple with some other metal in the system, while that galvanizing might protect the can itself, at the same time may be chewing up some other portions of the system, due to the galvanic action?

Morgan B. Smith.—Yes, depending somewhat on the distance between the two metals, the galvanized can and the other metal generally being pretty close together, as in the case of ice cans and brine cooling coils in can-ice brine tanks.

F. L. Fairbanks.—We found that that took place in the case of Venturi meters 75 feet apart. We can trace the source of these currents pretty readily.

Morgan B. Smith.—I never found a case where the separation was as great as that, but if you have actually isolated the source of the current, there is no question about it.

F. L. Fairbanks.—It went through two Venturi meters 75 feet apart, and we tested around the various joints of the system until we came to the right point, and have now concluded that the elimination of all zinc is the only safe thing.

Morgan B. Smith.—In a previous paper I read before this Society I have cautioned against the use of galvanized iron. What I meant to bring out was that the zone of protection which the zinc affords to the iron is very limited. To show a concrete example, we have had cases in the laboratory where a small pinhole was evident on a sheet of galvanized iron, the zinc going into solution, showing a zone of protection about one inch diameter. That was the largest zone of protection that I ever saw in a case like that, so you can see that in the case of a large surface of galvanized iron the actual protection afforded by the zinc would be comparatively slight.

F. L. Fairbanks.—I notice that you called attention to the fact that the brass-iron combination gave less drop in weight than the copper-iron? We have tried condensing tubes in which we had that combination, but we dropped brass, for the reason that, being an alloy of zinc and copper, it would not stand the galvanic action. We found in a year or two that the zinc had been entirely removed and what was left was practically pure copper.

Morgan B. Smith.—I am of the opinion that the alloys, possibly copper-iron or what we will more likely get, I believe, will be copper-steel, will be the solution of the corrosion problem, not an absolute solution, but a means of minimizing corrosion. One point brought

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out, I believe, in this work is the fact that aluminum gains in weight. In the alkali trade and the coal-tar industry I know of many pieces of appartus which are made of aluminum because that they are not attacked. I don't know that aluminum could be introduced into refrigerating apparatus, but it is a point that might bear looking into.

F. L. Fairbanks.—We have undertaken to use aluminum-lined tubes, but the quotations have been so high as to be absolutely prohibitive.

Morgan B. Smith. With aluminum-lined tubes you would be combining dissimilar metals, and you would probably run into trouble.

F. L. Fairbanks.—If you use aluminum absolutely pure you will have to change your methods of construction; you can't work it or thread it with safety.

Morgan B. Smith.—I don't know how that will work out, but, considering the advances made in metallurgy, it seems probable that this will be practicable before long.

F. L. Fairbanks.—Nickel would cover both points; we cannot only thread it, but we can roll it, but we can't afford to pay for it. We always come up against that; we can do almost anything if somebody furnishes the money, but when we work out a solution they cut the money off and we have to stop.

Peter Neff.—I would like to ask Mr. Smith what his experience has been with pumps handling calcium brine. Is brass or bronze or plain iron the best lining for pumps designed for that purpose?

Morgan B. Smith.—I would strongly recommend an all-iron pump or an all-brass pump. We have found in investigating corrosion difficulties that when pumps are made up with a cast-iron body lined with brass, the iron is invariably attacked, either slowly or rapidly, according to conditions. If you use an all-brass or all-bronze pump, which would probably be prohibitive on account of cost, any action can be made to take place at the expense of a short iron fitting engaging that pump. I have seen that done very successfully where the piping was brought almost to the pump and a short iron nipple, flange or fitting put in. Perhaps the iron part would be eaten out, but the cost of repairs would be slight.

F. L. Fairbanks.—We were having trouble with our iron pumps, and so changed our brine circulating pumps to solid brass, about 1¼ inches thick. The first pump we changed was a 20 by 24. I don't know whether they paid any dividends that year or not. We put the pump in service, and the first thing we found was a very bad gal-

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vanic action, the zinc in the brass combination being removed rapidly, after which the metal was subject to fracture, due to the low temperature, and a shock resulting from a closed system. We found that the brass pump would fracture very nearly as quickly as the iron one did. We changed the second pump; the first was brass and the second bronze; that is, we eliminated the zinc. The composition was 88, 10 and 2, the 2 being lead. We found that that stood up very much better than the zinc combination and had very little trouble with fracture at low temperature. Now all of our later pumping engines are built entirely of a semi-steel, which is practically cast iron with a mixture of steel, and by the elimination of all zinc, that is to say, the plungers, cylinder linings, bushings and all trimmings of that sort, we find absolutely no indication of corrosion by galvanic action. We have one pumping engine that has been in service now steadily for five years. It was opened up about a week ago for inspection, and, as far as could be observed, the metal was just as sound as when it was started.

Morgan B. Smith.—At the St. Louis meeting I called attention to practically the same thing, and recommended the use of one metal as far as possible, a metal of as high grade of purity as possible and showing as little segregation of impurities as possible. I believe that that bears out Mr. Fairbanks' experience.

N. H. Hiller.—This same question of pumps, I think, was covered two or three years ago, and at that time the statement was made that a cast-iron pump with iron fittings throughout, but with a brass or bronze rod, would answer the purpose about as well as any construction that could be had. Iron rods cause trouble in calcium chloride when the pump stops, because of the high affinity that calcium chloride has for moisture, a slight film causing absorption of moisture and corrosion of that rod and fittings. A bronze rod obviates that difficulty, the only connection being between the piston and the rod. No bad results have appeared from that construction during the years we have used it.

Irving Warner.—I would like to ask Mr. Smith if he can suggest an alkaline re-agent for adding to the brine from time to time in order to preserve the alkalinity which he suggested was so desirable?

Morgan B. Smith.—I would recommend either quicklime or slack-lime or a very dilute solution of caustic soda. I would say that should be done with great care and preferably under the direction of a chemist, because of the fact that solutions of a certain

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alkalinity may, under certain conditions, exert almost as great an effect in accelerating corrosion as an acid solution.

Irving Warner.—Would a careful litmus paper test——

Morgan B. Smith.—No, litmus is not sensitive enough; it is not an indicator free from hydro-oxides. I would recommend phenolphthalein.

Irving Warner.—We have a system in our plate plant in which we use brine for melting the ice off pipes. There are a large number of fittings and valves, and though we have not been put to great expense, we have been put to sufficient expense to show us that this paper is of great value. I want to thank the author personally for what it has done for us. I wish to ask whether it would be possible to now and then insert rubber connections in order to prevent galvanic action in long lengths of pipe. In automobile practice they use a section of rubber pipe in their water circulating system, not for the same purpose, but to lessen vibration. It stands the heat and steam and strain very satisfactorily. Do you think we can do the same thing in a brine system?

Morgan B. Smith.—I think that can be done with some benefit; on the other hand, all parts will be more or less covered with moisture, and it seems to me that there will still be some danger, but I do believe that that will minimize it.

Henry Torrance, Jr.—I would like to know if Mr. Fairbanks' remarks applied to the brine or salt water, or both?

F. L. Fairbanks.—Both. We have tried to insulate our pipe lines as suggested, and we find that the lime, iron oxide, water, etc., build a bridge across and we are wasting our time. Nature seems to be against us.

Morgan B. Smith.—Speaking of the automobile troubles and efforts to prevent loosening due to vibration, so far as I know, in investigating the trouble the Winton people had—that was the car I had occasion to investigate—the use of rubber hose did not seem to have any very great effect. The trouble was a local action, largely in the radiator, where the solder was eaten out. Where we combine solder with dissimilar metals, the action goes on at the expense of the solder; that is, in the case of a motor car, on the forward side of the rubber connections. On the rear side we had brass and iron connections, and the iron connections suffered; so it seems to me that it is largely a question of local action in the case of automobile practice. Stray currents from the ignition circuits also appeared to exert some action tending to hasten corrosion.

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N. H. Hiller.—In speaking of rubber hose connections between the parts of an automobile, some of you who are interested in brewery refrigeration will find that oftentimes copper attemperators cause trouble where they are connected direct with the brine pipes, and if you put rubber connections between it will help. That has been the experience of several breweries that I know of.

Henry Torrance, Jr.—I would like to ask Mr. Fairbanks if he did not have a set of atmospheric condensers subject to salt water action for a long time, which lasted very well, and whether they produced corrosion in some other parts?

F. L. Fairbanks.—Yes, they lasted very well, but it cost us about $15,000 a year for ammonia, and we could have bought a new set of condensers for a couple of thousand.

Henry Torrance, Jr.—What I had reference to was the original bank of condensers put in by De La Vergne a long while ago, and I understood that they lasted very well.

F. L. Fairbanks.—They did, unusually well, and I never could find out why it was. We tried it again and lost on it. If we get a year out of the ordinary galvanized coil in our service we are doing very well, and in the last three years we are not getting more than eight to nine months out of a set of coils in either the absorber or condenser.

Fred W. Wolf.—I will tell you of an experience I have had that may be an example. For use in connection with Waukesha water I was to furnish a galvanized pipe cooler. At the time the order was placed a sample length of galvanized pipe was laid in the water, and it was only two or three days before what coating there had been on it was removed by the chemical action of the water setting up electrolysis. Although the original was to be placed in any event, some Kalemein pipe was tried and a Kalemein pipe cooler built, but before it could be delivered the Kalemein samples had also reacted, and because the original galvanized cooler was still tight, it was decided to try galvanizing the Kalemein cooler. It just happened that this cooler was ready to ship, so it was galvanized in one piece. It arrived just as the galvanized cooler breathed its last. The cooler lasted six years, and only last summer a similar difficulty was experienced because these results had been forgotten.

President Shipley.—That was the point Mr. Smith made, that by galvanizing after the apparatus is assembled, the coating is uniform all over and there are no breaks at the couplings. Possibly that is the solution of your troubles.

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F. L. Fairbanks.—I would like to qualify my statement to Mr. Torrance. I think I know why that condenser lasted so long, for six or eight years; it had never been cleaned, and the Boston Harbor water, which we use, carries quite a portion of silt and clay, and we find that if the coils are not cleaned it will build up a scale of this earthy matter, which seems to protect it. We also found that true in some of the first coils we used; that is, if they were not cleaned at all, and there was a lime or a clay coating formed inside, apparently no corrosion whatever took place, but in about two years the coil would be plugged up tight. Perhaps he remembers some coils that were cleaned by plugging both ends and putting them in the fire. We figure that we lost about ten times what the coils cost in efficiency, that is, in the coal bill.

We find further that either in straight tubes or coils, the destruction seems to be directly proportional to the cleaning. For the last five or six years we have one man at each station who does nothing but keep condenser and absorber coils clean. He works on the open coils with a brush all the time. We blow out the coils in the absorbers and straight-tube condensers with air about twice a week, the same as you blow boiler tubes to keep them clean, and I find that it results in ten to twenty pounds' lower head pressure on our compressors and a very much higher efficiency. It becomes a question whether to keep the coils clean and lose them at one end, or let them get coated and lose coal at the other. I think it would attract less notice to lose at the coal pile, because we expect to buy coal, anyway.

Louis Block.—I should like to ask Mr. Fairbanks whether he really meant to say that the condensers did last but one year.

F. L. Fairbanks.—They lasted but eight months.

Louis Block.—Is there anything peculiar about the Boston Harbor water?

F. L. Fairbanks.—Very much so; there is considerable free chlorine, some salts of ammonia, that is to say, we take our condensing water, of course, from under one of the wharves; our Richmond street plant takes its condensing water from under Mercantile wharf, which is a fish wharf. We find that the action there is considerably greater than at the Sargent's Wharf plant, where the water is cleaner. There we have our own dock and fishing vessels do not dock in the vicinity.

Louis Block.—Then the explanation of why the first set of condensers lasted so long is because they were kept dirty?

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F. L. Fairbanks.—Yes, sir, I think so. They didn't last two seasons after I put men on the job to clean them.

Louis Block.—How long did they last before that?

F. L. Fairbanks.—I think five, six or seven years. I don't know exactly.

Louis Block.—The condensers in New York last twelve or fourteen years.

F. L. Fairbanks.—I have a letter from the Merchants' Refrigerating Company, in Jersey City. They seem to be in about the same fix.

George A. Horne.—We have had quite a variety of experiences with coils, pipes and pumps. I don't want to get away from the subject of pumps myself; it is a very interesting one to me. We have been led to think there must be a decided difference in the iron in different coils and tubes in different vessels. We have, in one of our New York plants, a set of coils that have been in operation since 1898. We keep them as clean as we can and we have never lost a coil, and have been running continuously for fifteen years. We have other coils that have gone in two seasons, with exactly the same service and the same kind of water. We had forty tubes in an absorber that went inside of eight months, pitted right through in certain spots. That is in New York, not in Jersey where we have the salt water. With the very same water going through, another set of coils has lasted fifteen years. I want to ask Mr. Smith if there is anything in connection with the composition of the iron that could in any way make such a tremendous difference as that. But, to get back to the pumps, which are along the same line. I think there are two distinct kinds of action, corrosion and electrolytic action. Just as Mr. Fairbanks said, in some of our pumps the valve decks get so soft in two or three years that you could poke a knife right through them. That is in Jersey City. I have other pumps, with brass fittings, pumping identically the same brine, that have been in use for twenty years, and the valve decks are just as good as the day they went into the pump. The pumps stand side by side. In one pump the valve decks and part of the pump back of the lining are just like cheese, and in another pump right alongside of it, pumping the same brine, they are in fine condition. Now, I would like to know if the composition of the iron or steel can be responsible for that.

Morgan B. Smith.—The way I look at the question of iron is again from the standpoint of local cell action, especially in the case

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of cast iron. The more impure the cast iron, and the greater the segregation of the impurities, the faster will be the attack on cast iron, due to the fact that you have myriads of little battery cells. I drew at one time, I believe, on this floor, or else at St. Louis, the analogy between this action and that of the ordinary doorbell battery. You take a solution of salammoniac, which is nothing but brine, put into that two dissimilar metals, carbon and zinc; the action, of course, goes on at the expense of the positive metal, zinc; the carbon remains. In the case of cast iron, the reaction will go on at the expense of the iron, and the impurities, slag, etc., will remain. If that goes on long enough, you will have left the form of the fitting, but it will be so soft you can cut it with a knife; so I am firmly convinced that the metal used should be, as far as possible, one metal; that the impurities present should be as small as possible in percentage content, and that the degree of segregation should be as little as possible.

F. L. Fairbanks.—I would like to ask Mr. Smith if it is possible to get corrosion without a flow of current? Do you know of such a case? I have never seen one.

Morgan B. Smith.—I think corrosion can be started by such agents as free carbon dioxide gas.

F. L. Fairbanks.—Without the meter showing it?

Morgan B. Smith.—It is not likely that a condition could exist in which no current could be found.

F. L. Fairbanks.—Then, as far as anything we have, shows, it is assumable that all corrosion is accompanied by galvanic action?

Morgan B. Smith.—Yes, I believe I have Dr. Walter back of me in this assertion, that corrosion is primarily an electrolytic action, in which case the metal will travel with the current.

F. L. Fairbanks.—Then, undoubtedly, if we stop one we stop the other.

Morgan B. Smith.—I believe so. Mr. Fairbanks, I wish to ask you a question in regard to the water you use from Boston Harbor. Is the presence of free chlorine common to Boston Harbor or is it a purely local condition?

F. L. Fairbanks.—I don't think it is common outside of the fish wharves and those sections where they are allowed to dump offal overboard, so that we get practically sewage. We get that practically all along the Atlantic avenue front, due to the decomposition of animal matter.

Morgan B. Smith.—In other words, if you could be sure of

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getting the water further out in the harbor you might eliminate a good deal of that trouble?

F. L. Fairbanks.—Unquestionably. In the winter time, when we get a very strong current towards Charlestown at Sargent's Wharf, there is a circulation of comparatively clean water from the harbor in there, and we have very much less trouble.

N. H. Hiller.—Paragraphs 8, 9 and 10 are very important, because they are the ones which answer such questions as those asked by Mr. Horne. I remember going into one of the plants that Mr. Horne speaks of some ten years ago, and the engineer showing me that by taking one wire of an electric light he could get current enough to light up an incandescent bulb. I believe later it was found there was some difficulty with the conduits in that street. Everyone troubled with corrosion should make special efforts to determine whether there are any electric leaks.

Charles H. Herter.—Has anybody had any experience with lead lined iron pipe?

F. L. Fairbanks.—We had three or four thousand feet of it, two, three and four inch, particularly in water jacket overflows for compressors, and took out some that had been in service possibly twelve or fifteen years, in which the pipe seemed to be as perfect as it was when it was put in, with the exception of the ends where it was coupled. Other sections were completely rotted out, the lead lining having had no beneficial effect whatever. The apparent cause was that it is impossible, practically, to lead line a pipe so that it is perfectly lined. If the iron is absolutely covered it does seem to protect it, but if the lead has a loose spot or poor spot and your salt water gets to the iron, the liquid is then apparently segregated and becomes more or less acid, and if there is anything there to decompose, the action is quicker than it would be without it. It was not satisfactory at all in our service.

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No 107

PHYSICAL PROPERTIES OF ANHYDROUS AMMONIA

By Lionel S. Marks and F. W. Loomis, Harvard University

(Non-Members of the Society)

In response to a request to prepare for the Society a statement of our present knowledge of those physical properties of anhydrous ammonia which are of importance to the refrigerating engineer, the following paper is offered. It contains the results of the most important experimental work published so far, some analysis of those results on thermodynamic and other grounds, and a critical discussion of the tables that have been prepared by various authorities. It is not possible to include in this paper a table which may be accepted as accurate, but an attempt has been made to ascertain which of the existing tables represents with greatest accuracy the available experimental data.

It is possible to proceed in a number of very different ways in an attempt to determine the physical properties of a fluid. The existence of certain thermodynamic relationships makes it unnecessary to determine experimentally all the desired properties, and permits the calculation of some when certain others have been determined by direct experiment. The most obvious method of obtaining a complete table is to determine experimentally the pressure--temperature relations of the saturated vapor, the specific volumes of the liquid and of the saturated and superheated vapors, the specific heats of the liquid and of the superheated vapor, and the heat of vaporization. If a table constructed from such data is thermodynamically consistent, it can be accepted with confidence. Unfortunately, however, the difficulties in the experimental determination of some of these quantities are considerable, and although all the above properties have been determined for ammonia by different investigators throughout certain limited ranges, the results are by no means consistent. Under these conditions the best means available for reconciling conflicting data is to smooth out inconsistencies by the use of empirical equations similar to those which have been found to represent accurately the corresponding properties of other

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and more perfectly investigated fluids. The information now available on the properties of different substances justifies us in expecting certain similarities in the relationships between given groups of properties for different substances.

There are two relationships of fundamental importance which have been much investigated for a number of substances. These are:

First.—The pressure-temperature relations of the saturated vapor.

Second.—The pressure-volume-temperature relations of saturated and superheated vapors.

These two relationships are most conveniently expressed by equations to which the names "vapor-pressure-equation" and "characteristic equation" may respectively be given.

It has been found that certain special types of equation give very satisfactory vapor-pressure and characteristic equations for a number of vapors on inserting the proper constants in the equations. It has been shown, moreover, that the closer the chemical relationship of two vapors, the greater is the resemblance in their physical properties. The vapor which has been investigated most thoroughly is that of water, and on this account it is desirable to take those equations which hold for water and to apply them to other fluids.

Ammonia is not closely related to water, although in some respects its physical properties are nearer to those of water than are those of any other known substance. This applies particularly to the specific heat of the liquid, the heat of fusion, the heat of vaporization and the critical pressure, for all of which water and ammonia have values exceeding those of any other substance. For the two properties first mentioned the values for ammonia exceed those for water; for the latter two the reverse is the case.

This is but very slight justification for the application to ammonia of empirical equations of the same form as those found satisfactory for water; but it will tend to increase confidence in the results if the empirical equations are found to agree well with the available experimental information.

The vapor-pressure equation is always based upon direct experiment, and does not require a very considerable body of observation. The characteristic equation, on the other hand, if based upon experimental determination of volumes, should have an extensive series of observations to justify it. It is, however, possible to determine the

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constants in a characteristic equation of any assumed form by means other than the use of direct measurements of the specific volumes of the saturated or superheated vapor. Most of the characteristic equations which have been used by various computers as the basis of their tables of the properties of ammonia have not been derived from direct volume measurements, but from measured or assumed values of coefficients of expansion and coefficients of compressibility, or from the so-called Joule-Thomson effect, obtained from throttling experiments. Any of these procedures will give accurate results if only the experimental quantity used is accurately known throughout the pressure and temperature range covered by the tables.

Unfortunately, such complete knowledge of any one of these quantities is still wanting, so that none of the characteristic equations to date can be accepted as final. That equation, however, is to be preferred which best accords with the largest body of reliable experimental data.

Turning first to *the pressure-temperature relations* of saturated ammonia vapor, we find the following experimental observations, all of which have been transformed into English units for the convenience of the engineer.

The earliest experimental work is that of Faraday,[1] published in 1845, and is as follows:

Temperature, Degrees Fahrenheit.	Pressure, Pounds per Square Inch.
0.	36.43
26.1	59.34
48.9	85.65
82.9	147.0
120.9	151.3

The value of these observations is historic rather than intrinsic.

In 1862 Regnault[2] published the results of three series of experiments. At the end of the first series a leak was discovered in his apparatus, which suggests the possibility of error in the last observations of that series. It is needless to say that exceptional weight must be given to the work of this observer.

[1] Phil. Trans., 135, I, 155; 1845.
[2] Mem. d l'Institute de France. Vol. 26, p. 596, 1862.

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REGNAULT'S VAPOR-PRESSURE DETERMINATIONS

First Series.		Second Series.		Third Series.	
Temperature, Degrees Fahrenheit.	Pounds per Square Inch.	Temperature, Degrees Fahrenheit.	Pounds, per Square Inch.	Temperature, Degrees Fahrenheit.	Pounds, per Square Inch.
32.0	62.04	−23.8	16.21	50.0	88.04
32.0	62.13	−24.5	15.93	57.9	102.6
32.0	62.03	−24.7	15.76	67.5	122.3
32.0	62.18	−17.3	19.47	86.9	170.4
32.0	61.86	−17.5	19.40	102.0	218.1
− .4	29.49	−8.9	24.07	120.0	285.3
+2.8	31.23	−8.7	24.21	131.9	337.8
2.1	31.53	−1.1	29.36	147.9	421.9
8.4	36.75	−1.1	29.28	170.0	523.0
10.1	38.31	+13.3	41.00	179.1	629.5
39.2	69.93	13.1	41.27		
40.5	73.73	32.0	61.95		
		32.0	62.02		
		44.4	80.07		
		45.1	81.24		
		45.1	81.19		
		47.3	84.50		
		52.5	93.53		
		56.3	103.2		
		64.8	118.6		
		66.7	123.8		
		66.7	123.4		
		77.7	148.5		
		90.9	185.1		

Pictet [3] published the results of his experimental determinations in 1885. They are in close agreement with those of Regnault.

Blumcke [4] in 1888 published the following observations:

Temperature, Degrees Fahrenheit	Pressure, Pounds per Square Inch.
−1.3	28.07
32.0	62.02
93.2	188.15
146.3	412.1

Next in importance to Regnault is the work of Brill [5], published in 1906. This work was carried on at very low temperatures, namely, from —27.4° Fahr. to the melting temperature at about —108° Fahr. The results are given in the following table. Brill, himself, regards his work at the lowest temperatures as better than that at higher temperatures. He experienced difficulty in keeping temperatures constant at the higher temperatures, and admits an

[3] Nouvelles Machines frigoriques, Genève, 1885.
[4] Wied. Ann 34, 10; 1888.
[5] Ann. der Phys., 21, 172; 1906

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error of about .4° Fahr., which would give an error of one to two per cent. in the pressure. An actual plotting of his observations, however, shows a deviation which is sometimes as great as three per cent. from the best possible curve drawn through them.

Temperature, Degrees Fahrenheit.	Pressure, Pounds per Square Inch.
−112.	.681
−110.2	.735
−107.7	.853
−103.2	.988
−99.2	1.209
−94.7	1.448
−90.9	1.692
−83.9	2.143
−81.1	2.630
−77.4	3.048
−75.1	3.334
−69.7	4.061
−65.9	4.632
−59.3	5.984
−51.2	7.803
−49.0	8.454
−42.7	10.09
−39.6	10.99
−36.8	11.80
−27.4	14.72

J. H. Davies,[6] in an appendix to a paper published by Perman & Davies, in 1906, gives the following observations:

Temperature, Degrees Fahrenheit.	Pressure, Pounds per Square Inch.
−57.6	5.76
−41.8	10.27
−22.0	16.77
−4.0	26.94
+5.0	33.38
14.0	41.50
23.0	50.61

Scheffer,[7] in 1910, states that he made some determinations of the pressure-temperature relations of the saturated vapor and found that his results agreed with Regnault and Pictet within their limit of error. He does not state the range covered.

Besides these observations there are various determinations of *the boiling point* of ammonia—that is, of the temperature of ebullition at the standard atmospheric pressure. The data from these observations are collected in the following table:

[6] Roy. Soc. Proc. Ser. A, 78, p. 41; 1906-7.
[7] Zeit. für Phys. Chem., 71, p. 694; 1910.

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BOILING POINTS

	Date.	Boiling Point, Degrees Fahrenheit.
Loir & Drion[8]	....	−32.3
Joannis[8]	....	−36.8
Brill[9]	1906	−27.6
de Forcrand[10]	1907	−26.5
Gibbs[11]	1905	−28.3
Davies[6]	1906	−28.3
Franklin[12]	1906	−28.3
Dickerson[8]	1907	−27.4

The *critical pressure and temperature* have also been determined by a number of investigators. The following table contains their results:

CRITICAL DATA

	Date.	Critical Temp., Degrees Fahrenheit.	Critical Pressure, Atmospheres.
Dewar[13]	1884	266.	115.0
Vincent & Chappuis[14]	1886	267.8	113.0
Guye[15]	1908	270.1	109.6
Scheffer[16]	1910	269.8	111.3

For the sake of completeness there may be included here also the determinations of the melting temperature of ammonia:

	Melting Temperature Degrees Fahrenheit.
Holborn & Wien[17]	−109.8
Ladenburg & Krugel[18]	−106.7
Ladenburg & Krugel (corrected)[19]	−103.9
Dickerson[20]	−106.6
Brill[21]	−107.9

[8] Quoted in L. Bronn "Verflüssigtes Ammoniak als Lösungsmittel," Berlin, 1905.
[9] Ann. der Phys., 21, p. 176; 1906.
[10] Ann. der Phys., 24, p. 367; 1907.
[11] Jour. Am. Chem. Soc.; 1905.
[12] Wied. Ann., Vol. 24; Jour. Phys. Chem., 11, p. 553; 1907.
[13] Phil. Mag. (5), 18, 210; 1884.
[14] Jour. de Phys. (2), 5, 58; 1886.
[15] Comp. Rend., 145, p. 511 and 703; 1908. Also Centralblatt, 1908, p. 713.
[16] Zeit. f. phys. chem., 71, p. 694; 1910.
[17] Wied. Ann., 59, p. 213; 1896.
[18] Ber. d. deutsch. chem. Ges., 32, p. 1818; 1899.
[19] Ber. d. deutsch. chem. Ges., 33, p.637 ; 1900.
[20] Cp. O'Connor Sloane, Liquid Air and Liquefaction of Gases. London, 1900.
[21] Ann. d. Phys., 21, p. 170; 1906.

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All the experimental points given above are shown in Fig. 1, plotted in a special way. A certain vapor-pressure equation suggested by Wobsa, to which reference will be made later, has been chosen arbitrarily to give saturation pressures corresponding to various temperatures and the percentage deviation of all the experimental points from the calculated Wobsa values have been plotted. On the same figure have been drawn a series of curves, showing deviations from Wobsa of the pressures calculated from a number of other equations. It is obvious that that curve which most nearly follows the experimental points on this diagram will best represent the experimental data.

The Regnault,[22] Zeuner[23] and Wobsa[24] equations are of the form

$$\log_{10} p = a - b\alpha^t - c\,\beta^t,$$

and the constants in these equations are given in the following table:

	a	$\log_{10} b\,\alpha^t$	$\log_{10} c\,\beta^t$
Regnault....	3.8446714	0.3747469 − .0019457t	term absent
Zeuner.....	3.8446665	0.3747428 − .0019457t	term absent
Wobsa.....	9.7947	0.8704939 − .0002214t	− .04742 − .0033055t

The Rankine[25] curve is calculated from the following equation, which is of a form suggested by Rankine:

$$\log_{10} p = 11.17994 - \frac{2609.694}{T} - 1.8726 \log_{10} T.$$

The units in the above equations are pounds per square inch and degrees Fahr.

Examining the Regnault curve, it will be seen that in the range from about 180° to about 60° Fahr. it represents the experimental values very well, except for a number of points from his own second series, but that below 60° Fahr. the curve begins to depart systematically from his own observations, and also from those of Brill and others. There seems no question but that his equation should be rejected except for the range from 60° to 180°.

The curve based upon the Rankine equation does not fit the experimental data very satisfactorily. It is too high about 100°, too low from 70° to —40°, and below —90° there is a rapidly increasing error.

[22] Loc. cit.
[23] Grundzüge der Mechanischen Wärmetheorie.
[24] Zeit. d. ges. Kälteindustrie, 15, p. 11; 1908.
[25] Juliusburger, Ann. der. Phys. (4), 3, p. 643.

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The Zeuner equation is similar to that of Regnault with but slight changes in the constants. The curve shows poor agreement with the experimental data and departs rapidly above 160° and below —40° Fahr. from the indications of direct experiment.

The Mosher curve is obtained from the equation[26]

$$\frac{1}{T_a} = 1.70356 \frac{1}{T_w} - .0002242.$$

In this equation T_a and T_w are the absolute Fahrenheit temperatures for saturated ammonia and water vapors respectively, corresponding to the same pressure. It is based upon the so-called Temperature Ratio law.[27] This law, which has been found to give good approximations for a number of substances, states that for a certain pair of substances, if the reciprocals of the saturation temperatures corresponding to each of a number of different pressures be plotted against one another, the points will fall on a straight line. If the saturation pressure of one substance is known accurately at all temperatures, and is also known for a second substance at any two temperatures, it is possible to find the saturation pressure for the second substance at all other temperatures.

Mosher finds that this law is true for water and ammonia and is expressed by the equation given above. The pressure-temperature relation for water vapor, which he used in demonstrating the applicability of this law to ammonia, is that given by one of the present writers.[28] It will be seen that the Mosher curve fits the experimental data fairly well below 80° Fahr., but gives values which are too high above that temperature.

The Wobsa curve, from which deviations on the figure are measured, appears to represent the experimental data better than any of the other curves throughout the whole range from the freezing temperature to the critical temperature. The principal departures of experimental points from this curve are the Brill points from —36° to —80° Fahr., and some of the Regnault points from 56° to 90° Fahr. The deviation of the Regnault points is offset by the agreement of other points by the same investigator. In regard to the larger deviation of the Brill points, it should be remarked that these are the points which the investigator himself considered least

[26] Am. Soc. Refg. Eng., Dec. 1912.

[27] See Moss, Physical Rev., 25, p. 453; 1907.

[28] Marks, A. S. M. E., Vol. 33, p. 351.

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satisfactory; and that, although the percentage deviations are large, the absolute deviations are comparatively small on account of the low pressures of ammonia vapor at these low temperatures. Nevertheless, the error is greater than is to be expected in any good experimental work and could only arise from some source of systematic error.

In an attempt to get some light on the relative values of the Brill and Regnault points, the well-known van der Waals' equation

$$\log \frac{p_c}{p} = a \left\{ \frac{T_c}{T} - 1 \right\}$$

was used for the determination of the values of the constant a. For all substances of which the properties are well known, it has been found that the value of a obtained from this equation when plotted against the reduced temperature, $\frac{T}{T_c}$, lie either on a straight line or on a parabolic curve. When the values of a for ammonia obtained from the data of Brill and Regnault are plotted in this way, it is found that they lie on two curves which cannot be connected by any smooth curve. It appears, then, that the experimental work of one or both of these investigators should be looked upon with suspicion, and there seems very little doubt that this suspicion should fall upon Brill's work rather than Regnault's. Consequently, the deviation of Brill's points from the Wobsa curve should not be given too much weight. It should be noted that the Wobsa curve represents well the Brill points at the lowest temperatures, where, as pointed out already, they are undoubtedly most accurate. The Perman point at —58° Fahr. agrees well with the Wobsa curve and tends further to discredit the Brill points in the vicinity of that temperature.

It is not to be expected that the extrapolation of the Wobsa curve to the critical point should give results agreeing closely with the experimental data. The fact that the curve actually falls between the Guye and Scheffer points (the latest and probably the most accurate critical points) is, however, confirmation of the correctness of Wobsa's equation.

It would appear from the foregoing that the Wobsa equation may be accepted as representing existing data better than any of

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the other equations examined. It must be realized, however, that the experimental evidence indicates that it may be appreciably in error in the range from —25° to —90° Fahr. If the pressure is expressed in m.m. of mercury, and the temperature in degrees Cent., the constants of the Wobsa equation become

$$a = 11.5083$$
$$\log_{10} b\alpha^t = 0.863408 - .0003986\ t$$
$$\log_{10} c\,\beta^t = -0.15319 - .00595\ t$$

For the determination of *the characteristic equation*—that is, the pressure-volume-temperature relations of the vapor—various kinds of experimental evidence may be used. For ammonia the available experimental data include the following:

First.—The specific volumes in the saturated and superheated states.

Second.—The coefficients of dilatation $\frac{1}{v_0}.\left\{\frac{dv}{dt}\right\}_p$; of compressibility, $\frac{1}{v_a}.\left\{\frac{dv}{dp}\right\}_t$; and other similar coefficients.

Third.—The Joule-Thomson coefficient $\left\{\frac{dt}{dp}\right\}_H$, as obtained from throttling experiments.

Fourth.—The specific heat of the vapor.

Metric units have been retained for all the following experimental data and equations.

One series of observations only is available on the *specific volume of saturated vapor ammonia.* This was published in 1904 by Dieterici and Drewes.[29] The observations are given in the following table:

[29] Zeit. f. d. ges. Kälte-Industrie 11, p. 21, 1904.

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Temperature, Degrees Centigrade.	Specific Volume Cubic Cm. per Gm.
3.4	257.2
9.5	208.2
15.0	173.9
20.1	147.5
24.6	125.2
30.3	106.6
34.3	93.8
39.3	82.5
44.4	74.3
49.6	63.2
55.4	52.8
60.4	48.1
60.9	47.2
62.8	45.4
71.1	37.2
79.8	30.0
81.2	29.9
87.2	26.2
92.6	23.1
98.1	20.1
102.1	17.9
105.6	16.1

Specific volumes can also be found indirectly, from determinations of the latent heat of vaporization and the vapor-pressure equation, by the use of the Clapeyron equation:

$$u = J \frac{L}{T} \frac{1}{\left\{ \frac{dt}{dt} \right\}_{sat}}$$

The experimental determinations of latent heat are not numerous, nor are they particularly good. They include twelve observations by Regnault[30] grouped around three different temperatures, of which the averages are given in the following table:

Temperature, Degrees Centigrade.	Latent Heat, Cals.
7.8	294.21
11.04	291.32
16.0	297.38

The observations made by Regnault with an improved apparatus were all lost at the siege of Paris.

Strombeck[31] made six determinations at 17° C. and found a mean value of 296.5 cals.

[30] Ann. Chem. phys. (4), 24, pp. 428-438, 1871.
[31] Jour. Franklin Inst., p. 131, 1891.

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Franklin[32] found the latent heat at atmospheric pressure to be 341 cals.

Denton[33] deduced the latent heats at a number of different temperatures from the results of some experiments on ammonia compression machines, but his method was not such as to permit of any satisfactory degree of accuracy.

The Regnault latent heat values are so inconsistent as to indicate that they are quite untrustworthy. The work of von Strombeck is also open to suspicion. Consequently, the direct determinations of latent heat are of negligible value.

There is an empirical equation suggested by Thiesen[34] which has been much used for smoothing out experimental data on specific volumes. It is of the form

$$L = a\,(t_k - t)^n$$

where L is the latent heat at the temperature t, and t_k is the critical temperature. This form of equation has the advantage that it gives correct results at the critical points where we must have

$$L = O, \text{ and } \frac{dL}{dt} = -\infty$$

This equation has been found to represent very closely the data for a number of substances, and particularly for water vapor. It was used by Dieterici to test his values of the specific volumes of ammonia. He found that the equation

$$L = 27.15\,(t_k - t)^{1/3}$$

gave values of the latent heat which agreed with those deduced from the Clapeyron equation with an error not exceeding 1.3 per cent. from 0 to 100° C. He used the Zeuner vapor-pressure equation which, as we have seen, does not represent the experimental data very well. The values of the derivative from that equation, $\frac{dp}{dt}$, may be considerably in error. Consequently, this apparent verification of his observed volumes cannot be given very much weight.

[32] Jour. Phys. Chem., Vol. 11, pp. 553-558, 1907.
[33] A. S. M. E., Vol. 12, p. 326.
[34] Verh. Phys. Ges. zu. Berlin, Vol. 16; pp. 80-82, 1897.

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One series of observations only is available on the *specific volumes of superheated ammonia.* The work was carried out by Perman & Davies[35], and covers only atmospheric and lower pressures. Their results are:

Pressure Millimeters of Mercury.	Temperature, Degrees Centigrade.	Specific Volume, Cubic Cm. per Gm.
760	−20	1195.75
760	0	1297.3
760	50	1547.3
760	100	1796.4
380	0	2609.6

A number of investigators have determined the specific gravity or the density of ammonia at 0° Cent. and 760 millimeters pressure. Their results are summarized in the following table:

	Kilograms per Cubic Meter.
Thomson[36]	.7667
Biot & Arago[36]	.7713
v. Fehling[37]	.7655
Chem. Kalendar 1903	.7707
Perman & Davies[38]	.77085
Guye[39]	.7708
Leduc[40]	.7719

The data on coefficients of dilatation and compressibility are as follows:

Regnault[41] found that at 8.1° C. and for the range from 1 to 2 atmospheres pressure, $\frac{p_1v_1}{p_2v_2} = 1.01881$.

Lord Rayleigh[42] found $\frac{pv \text{ at } \frac{1}{2} \text{ atmos.}}{pv \text{ at } 1 \text{ atmos.}} = 1.00632$ at 9.7° C.

Perman & Davies[43], experimenting at constant volume and starting with a pressure of 722 millimeters of mercury at 0° C., found the following variation of pressure with temperature:

[35] Proc. Roy. Soc., Ser. A, Vol. 78, p. 28, 1906-7.
[36] Gmelin—Watts' Translation, p. 280.
[37] Dictionary of Chemistry, 1871.
[38] Loc. Cit.
[39] Comp. Rend., 141, p. 51, 1905.
[40] Comp. Rend., 125, p. 571; 1897.
[41] Mem. de l'Inst., Vol. 21, p. 329, 1847.
[42] Zeit. f. Phys. Chem., 52, p. 705, 1905.
[43] Loc. Cit.

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Temperature, Degrees Centigrade.	Pressure, Millimeters of Mercury.
98.1	991.3
80.	941.7
60.	887.9
40.	833.2
20.	778.4
−20.	664.2

Leduc,[44] experimenting at atmosphere pressure, found the value of $\frac{1}{v}\frac{dv}{dt}$ at 0° C. to be .003857, and its mean value between 0 and 100° C. 003797.

Starting with the gas initially at atmospheric pressure, he found $\frac{1}{p_0}\cdot\frac{dp}{dt}$ = .003801 at 0° C., and the mean value between 0 and 100° C. to be .003773.

The experiments of Perman & Davies already referred to give the following value of $\frac{1}{v_0}\cdot\frac{\Delta v}{\Delta t}$ at atmospheric pressure:

Between 0 and −20° C. = .003914.
Between 0 and 100° C. = .003847.
Between 0 and 50° C. = .003854.

Roth[45] determined the relative volumes of ammonia at different pressures and temperatures. His results are incorporated in the following table:

Pressure in Atmospheres.	Volumes At 99.6 Degrees Centigrade.	Volumes At 183 Degrees Centigrade.
12.5	7635	....
15	6305	....
20	4645	4875
25	3560	3835
30	2875	3185
35	2440	2680
40	2080	2345
45	1795	2035
50	1490	1775
55	1250	1590
60	975	1450
65	....	1340
70	....	1245
75	....	1175
80	....	1125
85	....	1080
90	....	1035
95	....	995
100	....	950

[44] Comp. Rend., 148, p. 1173; 1909.
[45] Wied. Ann., 11, p. 1, 1880.

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Information on the Joule-Thomson coefficient has been obtained only in the throttling experiments of Wobsa.[46] These results are summarized in the following table:

JOULE-THOMSON COEFFICIENTS.

Temperature, Degrees Centigrade.	Pressures in Kgs. per Square Centimeter.								
	2	3	4	5	6	7	8	9	10
6.....	3.58	3.55	3.52	3.49					
16.....	3.23	3.21	3.19	3.17	3.15	3.13	3.11		
30.....	2.93	2.91	2.89	2.87	2.85	2.83	2.81	2.78	2.76
40.....	2.73	2.71	2.69	2.67	2.65	2.63	2.61	2.59	2.57

The figures in this table have been smoothed out from the experimental observations on the assumption that the coefficient is a linear function of the pressure at any temperature. There is no very satisfactory way of testing the reliability of these observations. It has been shown by Buckingham[47] that if the pressures and temperatures are expressed as fractions of the critical pressure and temperature—that is, as reduced pressures and temperatures—the Joule-Thomson coefficients of different gases all fall on the same curve, when plotted against reduced temperatures. A portion of this curve has been plotted recently by Davis,[48] using all the available data on water and carbon dioxide. The plotted points are reproduced in Fig. 2, and there are added the results of Wobsa's experiments expressed in the same manner. The short vertical lines represent Wobsa's points, the length of the line indicating the variations in the values of the coefficients at each of the four temperatures investigated. It will be seen that these short lines suggest a systematic departure from the well marked trend of the Davis points. This departure does not, of course, demonstrate any inaccuracy in Wobsa's results, but it would seem to indicate the desirability of confirmatory data.

In using these coefficients to determine the constants of the characteristic equation, it is first necessary to have some information on the specific heat of ammonia vapor at constant pressure. For this

[46] Zeit. ges. Kälte-Industrie 14, p. 61, 1907.
[47] Bul. Bureau of Standards, Vol. 3, p. 239, 1907.
[48] Proc. Am. Acad., Vol. 45, pp. 243-264, 1910.

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there is available the work at atmospheric pressure of Keutel,[49] Voller,[49] Wiedemann,[50] Regnault and Nernst.[51]

The following table, based upon Nernst, gives the experimental values of these observations and shows the agreement between their data and the values calculated by the following equation, which was suggested by Nernst:

$$Cp = .505 + .00017\,t + .424\frac{t^3}{10^9}.$$

SPECIFIC HEAT OF SUPERHEATED VAPOR

Name.	Temperature Range, Degrees Centigrade.	Specific Heat at Constant Pressure.	
		Observed.	Calculated from the Equation.
Keutel	20	.506	.508
Voller	20	.505	.508
Wiedemann	25–100	.518	.512
Wiedemann	25–200	.534	.518
Regnault	24–216	.511	.521
Nernst	365–567	.610	.604
Nernst	480–680	.656	.656

There is no experimental information available as to the specific heat of superheated ammonia vapor at pressures other than atmospheric pressure.

All characteristic equations are based upon the perfect gas law

$$pv = RT$$

which is known to be approximately true for highly superheated vapors, and is less and less true as these vapors approach saturation. To adjust this basic equation to the observed deviations from the perfect gas law, various correction terms have been used by different authorities. The correction term has been assumed by some to be a function of the pressure; by others, of the temperature; and by still others a function of both these quantities.

Zeuner, as a result of his analysis of the then available data on the properties of superheated steam, adopted a characteristic equation of the form

$$pv = RT - Cp^n$$

the correction term of which is a function of the pressure only.

[49] See Nernst's paper.
[50] Wullner, Lehrbuch der Experimentalphysik, 5th Ed., Vol. 2, p. 529.
[51] Zeit. für Elektrochemie, Vol. 16, pp. 96-110, 1910.

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This equation was used in the calculation of the earlier tables of the properties of ammonia, including those of Ledoux,[52] Zeuner[53] and Peabody,[54] and in the range below 0° C., in the table of Lorenz.[55] Later investigations on steam show that Zeuner's equation is not satisfactory, so that the primary justification for its use for ammonia has disappeared. This, of course, does not show it to be unsuitable for that vapor.

Wood[56] assumed a characteristic equation of the form

$$pv = aT - \frac{b}{v^n},$$

in which the correction term is a function of the volume only.

According to van der Waals the perfect gas equation is not a true characteristic equation, because it fails to take into account the size and the mutual attractions of the molecules. Modifying the values of v and p, to take those factors into account the perfect gas equation becomes

$$\left\{p + \frac{b}{v^2}\right\}(v - a) = RT,$$

or

$$p = \frac{RT}{v - a} - \frac{b}{v^2}.$$

This equation has been found to give a much closer approximation to the experimental facts than the perfect gas equation.

Clausius modified this equation to

$$p = \frac{RT}{v - a} - \frac{cf(t)}{(v + b)^2}.$$

This modified equation was used by Mollier[57] as a characteristic equation for ammonia.

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[52] Theorie des Machines a froid, 1878.
[53] Zivilingenieur, p. 449, 1881.
[54] Thermodynamics of the Steam Engine.
[55] Technische Wärmelehre, 1904.
[56] Thermodynamics, 1889.
[57] Zeit. ges. Kälte Industrie, Vol. 2, p. 89, 1895.

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The latest tables have the advantage of being calculated after a considerable increase in our knowledge of the properties of steam. Two characteristic equations are now available for steam which represent very satisfactorily its properties as now known. The earlier of these was suggested by Callendar, and is of the form

$$v = \frac{RT}{p} - c\left\{\frac{273}{T}\right\}^n$$

It does not represent the facts quite so well as the equation of Linde, which was based upon the most recent accurate determinations of specific volumes. The Linde equation is of the form

$$v = \frac{RT}{p} - (1 + ap)\left[c\left(\frac{273}{T}\right)^n - D\right]$$

Both of these equations have been used for ammonia.

Wobsa[58] used the Linde equation at first, but in a later paper[59] he adopted the equation

$$v = 0.0075 + \frac{49.736T}{p} - \frac{2450}{T^2} + \frac{80}{p}.$$

Hybl[60] uses the Calendar form of equation:

$$v = \frac{49.7T}{p} - 0.208\left\{\frac{T}{273}\right\}^{2.22}$$

In these equations pressures are in kgs. per sq. m. and volumes in cu. m. per kg.

In order that a characteristic equation should cover any considerable range with a satisfactory degree of accuracy, it is necessary that it should be of the right form. It is even more necessary that the correct constants should be substituted in the equation, if accuracy is to be obtained even throughout a limited range. The earlier equations of Ledoux, Zeuner, Peabody, Wood and Mollier are all based upon extremely scanty experimental data, and are in fact necessarily based in part upon assumptions without any experimental verification. The data available to them was Regnault's coefficient

[58] Zeit. ges. Kälte Industrie, Vol. 14, p. 61, 1907.
[59] Zeit. ges. Kälte Industrie, Vol. 15, p. 11, 1908.
[60] Zeit. ges. Kälte Industrie, Vol. 18, p. 161, 1911.

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of compressibility at one temperature only; some data on specific volumes at atmospheric pressure and 0° C.; and Regnault's value of specific heat at constant pressure measured at atmospheric pressure only. This is scant information on which to base a characteristic equation, and it is not to be wondered at that the earlier tables show many divergences as between themselves.

The publication of Dieterici's observations on the specific volumes of saturated ammonia in 1904 was the beginning of an adequate basis for a characteristic equation. Dieterici published a table of the properties of ammonia, calculated directly from his observations, without the use of a characteristic equation. This is an entirely satisfactory procedure, but does not give any information on the properties of superheated vapor.

The work of Perman & Davies on the specific volumes of superheated ammonia in 1906, and the throttling experiments of Wobsa in 1907, have given a body of information which should serve to determine the characteristic equation with a greater degree of accuracy. The two equations of Wobsa and that of Hybl are based on this larger body of experiments. In so far as they represent accurately this experimental information, they must be given preference over any of the earlier equations. It is possible now to test them further by the use of the still more recent determinations of the coefficients of dilatation and compressibility.

The problem of deciding which of the proposed characteristic equations, and incidentally which of the available tables of properties of ammonia, is best, narrows itself down to a choice between the two Wobsa equations and the Hybl equation. Wobsa himself has chosen between his two equations, the later equation being published as an improvement on the earlier one. The agreement of the later equation with the data of Perman & Davies is better than that of the earlier equation. Both equations agree equally well with Wobsa's own throttling experiments, and also with Dieterici's experiments on saturated vapor. It should be pointed out, however, that Wobsa used his own pressure-vapor equation in conjunction with his later characteristic equation in the calculation of the specific volumes of the saturated vapor, but used Regnault's vapor-pressure equation in conjunction with his earlier characteristic equation. Since it has been shown already that Wobsa's vapor-pressure equation is more accurate than Regnault's, the agreement with Dieterici's

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observations would tend to support the choice of the second characteristic equation.

If we accept Wobsa's own judgment in this matter, the choice of characteristic equations narrows down to a choice between Wobsa's second equation and Hybl's equation. Hybl's process in the selection of a characteristic equation is somewhat peculiar. He plotted the specific volumes of saturated vapor, and of superheated vapor at 400° C. absolute, as calculated from the two Wobsa equations, from Ledoux's equation, and from other equations of the form of the Tumlirz, van der Waals and Callendar equations. He finds that the Callendar equation gave values which are approximately the mean between those obtained from the other equations, and, consequently, decided to adopt the Callendar form; but he does not justify his choice by direct comparison with the experimental data. Furthermore, in the calculation of the specific volumes of saturated vapor he uses Wobsa's vapor-pressure equation, but smooths out the calculated pressures arbitrarily in a way which is not justified by any experimental evidence.

The only test of the value of Hybl's characteristic equation is, of course, its agreement with experiment. In the following table is given the comparison of Dieterici's specific volumes with the volumes calculated from the Wobsa equation, and also from Hybl's equation. The Hybl values above 40° C. are calculated, using Wobsa's vapor-pressure equation, in conjunction with Hybl's own characteristic equation.

Temp. Deg. Centigrade....	0	20	40	60	80	100
Dieterici.....	.2904	.1480	.0809	.0486	.0302	.0192
Wobsa.....	.2901	.1475	.0816	.0482	.0300	.0193
Hybl.....	.2906	.1480	.0815	.0492	.0301	.0188

It is obvious that there is not much to choose between the two equations in respect to their agreement with Dieterici.

Testing these equations further by comparison with Perman and Davies' values of specific volumes of superheated ammonia, we get the following table:

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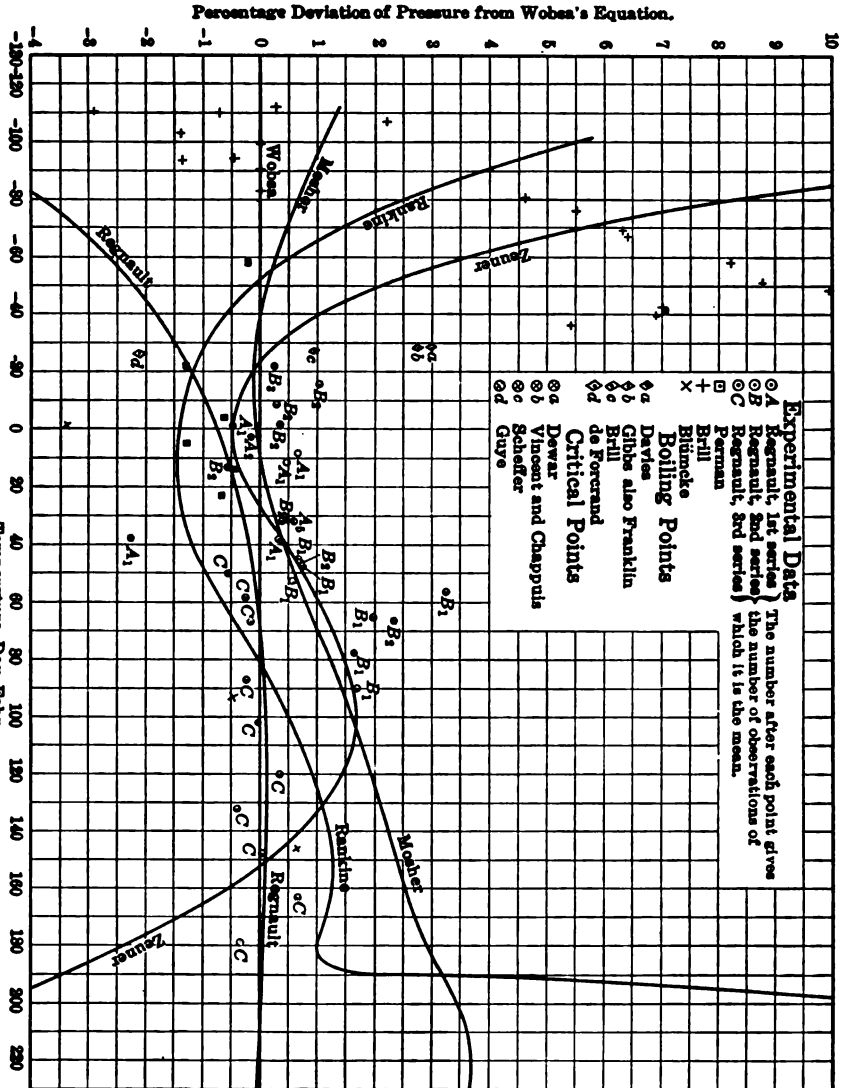

FIG. I

The percentage deviation of the experimentally determined pressures, and also of certain calculated values of the pressure of saturated ammonia vapor, from the pressures deduced from Wobsa's equation.

Temperature, Degrees Centigrade.	Pressure, Atmospheres.	Specific Volumes.		
		From Wobsa's Equation.	From Hybl's Equation.	From Experiment.
−20	1	1.1949	1.1923	1.19575
0	1	1.2965	1.2923	1.2973
50	1	1.5467	1.5396	1.5473
100	1	1.7933	1.7838	1.7964
0	½	2.6106	2.6054	2.6096

The Wobsa equation gives results which are consistently nearer the experimental values than those calculated from Hybl's equation.

The next test of the relative accuracies of the two equations is afforded by Wobsa's throttling experiments. The Joule-Thomson coefficients have been calculated at 6° C. and for pressures of two, three, four and five atmospheres, using Hybl's characteristic equation. The coefficient deduced from Hybl's equation is

$$\left(\frac{dT}{dP}\right)_H = A \frac{(n+1)\, c \left(\frac{273}{T}\right)^n}{Cp^\circ + n(n+1)\, Ac \left(\frac{273}{T}\right)^n \frac{P}{T}}$$

where n and c are the constants of Hybl's equation, A is the reciprocal of the mechanical equivalent of heat, and $C_p{}^\circ$ is given the value .49, which is assumed by both Hybl and Wobsa as the specific heat at low pressures. The calculated coefficients, and also those calculated by Wobsa, are given in the following table, together with the experimental results:

Joule-Thomson Coefficients
at 6° Cent.

Pressure, Atmospheres.	From Hybl's Equation.	From Wobsa's Equation.	From Wobsa's Experiments.
2	2.91	3.63	3.58
3	2.85	3.59	3.55
4	2.78	3.55	3.52
5	2.72	3.51	3.49

It will be seen that not only are the absolute values of the coefficients derived from Hybl's equation very wide of the facts, but also that the variation of the coefficient with pressure, which is less than one per cent. per atmosphere in Wobsa's experiments, is greater than

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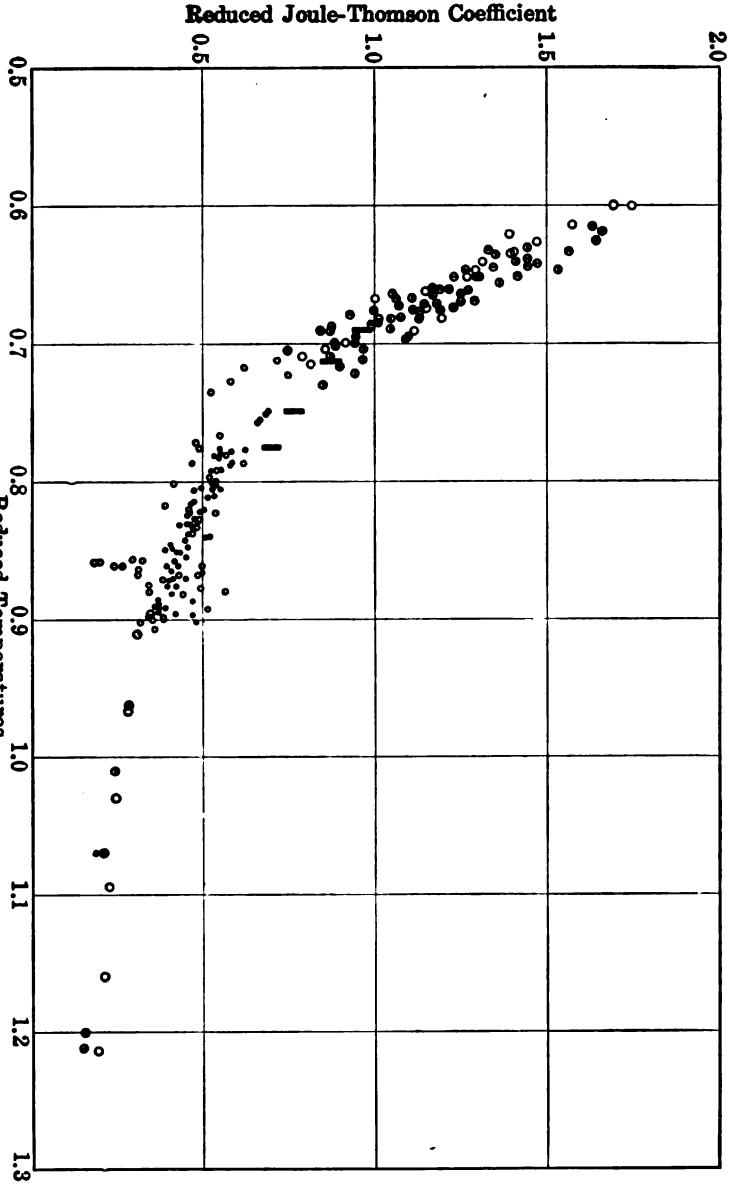

FIG. 2

Reduced Joule-Thomson Coefficient for water, carbon dioxide and ammonia.

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two per cent. in Hybl's equation. Wobsa's equation, on the other hand, represents the experiments very satisfactorily. It was not thought necessary to calculate the Joule-Thomson coefficients at the other temperatures investigated by Wobsa.

Further information on the relative accuracies of the Wobsa and Hybl equations may be deduced from the available data on coefficients of compressibility and dilatation.

Taking Regnault's value of $\frac{p_1 v_1}{p_2 v_2}$ at 8.1° C, and calculating the same quantity for the same pressure limits by both the Wobsa and Hybl equations, we get the following:

	$\frac{p_1 v_1}{p_2 v_2}$
From Regnault's experiment	1.01881
From Wobsa's equation	1.01792
From Hybl's equation	1.01485

For the coefficient of dilatation, $\frac{1}{v_0} \cdot \frac{\Delta v}{\Delta t}$, from 0° to 100° C. at atmospheric pressure we have the experimental data of Perman & Davies, and also of Leduc. A comparison with the calculated values of the same quantity is given below:

	$\frac{1}{v_0} \cdot \frac{\Delta v}{\Delta t}$
From Perman & Davies' experiments	.003847
From Leduc's experiment	.003797
From Wobsa's equation	.003829
From Hybl's equation	.003800

The mean of the experimental values agrees very closely with Wobsa, but not with Hybl.

The values of $\frac{1}{v} \cdot \frac{dv}{dt}$ and of $\frac{1}{p} \cdot \frac{dp}{dt}$ at 0° C. and one atmosphere as found by Leduc and as calculated from the two equations are given in the following table:

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	$\frac{1}{v} \cdot \frac{dv}{dt}$	$\frac{1}{p} \cdot \frac{dp}{dt}$
From Leduc's experiment.....	.003857	.003801
From Wobsa's equation.....	.003899	.003825
From Hybl's equation.....	.003853	.003535

The agreement of Hybl with Leduc in the first column is better than that of Wobsa. In the second column the Hybl value of .003535 shows a fundamental defect in the Hybl equation. For a perfect gas we have $\frac{1}{p} \cdot \frac{dp}{dt} = \frac{1}{T}$. For all imperfect gases this quantity has been found to be greater than $\frac{1}{T}$, or greater than .003663 at 0° C. It appears, then, that the correction term for the equation $\frac{1}{p} \cdot \frac{dp}{dt}$ deduced from the Hybl equation is of the wrong sign.

From an examination of the above, it will be seen that it is in the saturated region alone that the Hybl equation gives reasonably satisfactory results. In the superheated region it is seen to be inferior in accuracy to the Wobsa equation in the deduced values of specific volumes, of the Joule-Thomson coefficients, and also of the coefficients of dilatation and compressibility. Consequently, it has not seemed necessary to make further calculations with that equation.

The Wobsa characteristic equation is to be preferred as representing the experimental data with greater accuracy than any of the other equations considered.

The agreement of the Wobsa equation with other experimental data is shown below. The Wobsa equation gives the following values of pressure under the conditions of the Perman & Davies constant-volume investigation:

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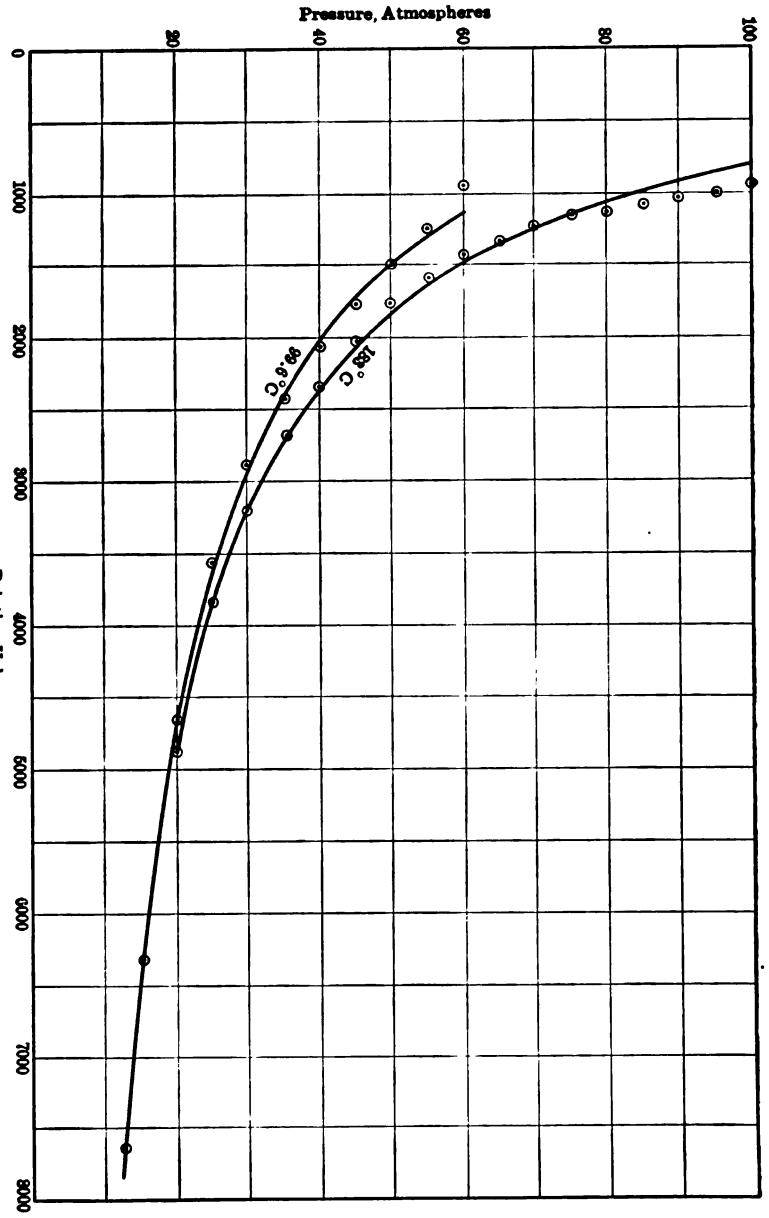

FIG. 3

Two isothermals for superheated ammonia vapor. The points show the experimental values of Roth; the curves are calculated from Wobsa's equation, and are located so as to coincide as closely as possible with the points. They represent unknown but different masses of the vapor.

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Temperature, Degrees Centigrade.	Pressure, Mm. of Mercury.		$\frac{1}{p_0} \cdot \frac{\Delta p}{\Delta t}$	
	Observed.	Calculated.	Observed.	Calculated
98.1	991.3	990.79	.003802	.003794
80.	941.7	941.28	.003804	.003800
60.	887.9	886.65	.003830	.003802
40.	833.2	831.80	.003850	.003809
20.	778.35	777.05	.003906	.003815
−20.	664.2	666.84	.004003	.003820

The calculated pressure agrees very well at the highest temperature, but shows a systematic departure at lower temperatures.

The agreement of Wobsa's equation with Roth's data is shown by Fig. 3. The plotted points are Roth's experimental points at two different temperatures; they give relative volumes at each temperature, but *not* specific volumes. The curves are calculated from Wobsa's equation and go through arbitrarily chosen starting points. These were chosen so as to make the curves coincide as nearly as possible with the experimental points. It will be seen that the agreement is not satisfactory.

The value of $\frac{pv \text{ at } \frac{1}{2} \text{ atmos.}}{pv \text{ at } 1 \text{ atmos.}}$ at 9.7° C., calculated from Wobsa's equation, is 1.00861, which shows very poor agreement with Lord Rayleigh's experimental value, 1.00632.

It will be seen that Wobsa's equation gives results which do not always agree with experiment. Taking into account the inconsistencies in the experimental data, it is probable that it is as good an equation as can be devised on the basis of existing information. Until further experiment supplies more exact data, there can be but little benefit in seeking a more accurate characteristic equation. It is not easy to decide as to the magnitude of the errors in the quantities derived from this equation, but it is probable that these errors are not large enough to be of any importance to the engineer in the saturated region. In the superheated region they may be of more importance.

In addition to the properties already considered, two other quantities are of importance in an engineer's discussion of the thermodynamic properties of ammonia. These are the specific volume or density, and the specific heat of liquid ammonia.

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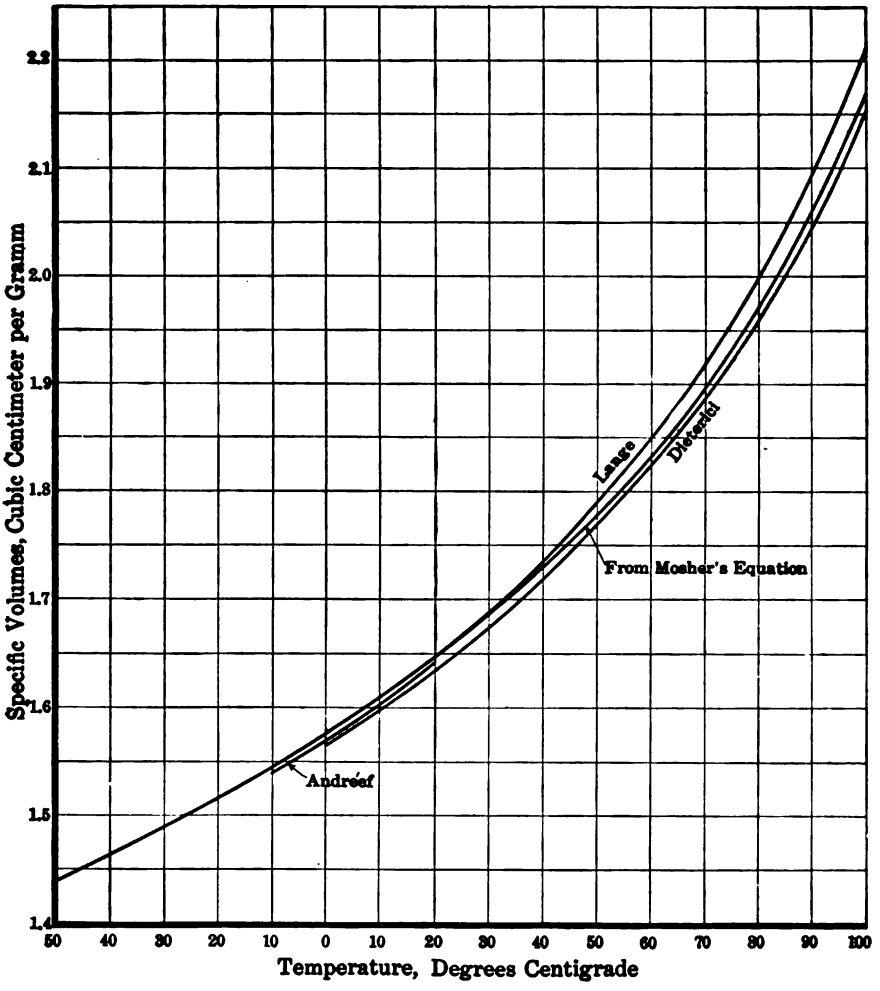

FIG. 4
Specific volumes of liquid ammonia.

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Early determinations of the *specific volume of liquid ammonia* include the following:

SPECIFIC VOLUMES OF LIQUID AMMONIA

	Date.	Temperature, Degrees Centigrade.	Density. Gms. per Cubic Cm.	Specific Volume. Cubic Cm. per Gm.
Faraday[61]	1823	10.	.76	1.316
		15.5	.731	1.368
Andréef[62]	1859	−10.	.6492	1.540
		−5.	.6429	1.555
		0.	.6364	1.571
		+5.	.6298	1.588
		10.	.6231	1.605
		15.	.6160	1.623
		20.	.6089	1.642
Jolly[61]	1861	0.	.6234	1.604
Lunge[63]	....	20.	.615	1.626
Lange and Hertz[64]	1897	Boiling Point.	.68	1.471

The most important determinations are those of Lange[65] in 1898, and of Dieterici and Drewes[66] in 1904:

SPECIFIC VOLUMES OF LIQUID AMMONIA. LANGE

Temperature, Degrees Centigrade.	Volume Cubic Cm. per Gm.	Temperature, Degrees Centigrade.	Volume Cubic Cm. per Gm.
−49.	1.440	28.4	1.684
−35.	1.475	32.6	1.702
−32.5	1.483	36.7	1.722
−31.2	1.488	40.8	1.742
−25.	1.504	44.7	1.763
−16.2	1.530	48.6	1.784
−10.2	1.541	52.5	1.805
−6.	1.561	56.4	1.827
0.	1.577	60.2	1.850
6.	1.598	63.6	1.873
7.9	1.609	71.6	1.930
14.7	1.628	75.8	1.962
19.4	1.647	78.8	1.987
23.9	1.665	81.8	2.014
		84.7	2.041
		90.2	2.096
		97.8	2.185

[61] Gmelin, Handbuch der Chemie.
[62] Ann. Chem., u. Pharm., 110, p. 1; 1859.
[63] Taschenbuch für Sodaindustrie.
[64] Zeit. f. angewand. Chemie, p. 227; 1897.
[65] Zeit. f. ges. Kälteindustrie, 5, p. 39; 1898.
[66] Zeit. f. ges. Kälteindustrie, 11, p. 21; 1904.

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SPECIFIC VOLUMES OF LIQUID AMMONIA. DIETERICI

Temperature, Degrees Centigrade.	Volume Cubic Cm. per Gm.	Temperature, Degrees Centigrade.	Volume Cubic Cm. per Gm.
0.	1.566	55.4	1.809
3.4	1.577	60.4	1.829
9.5	1.598	60.9	1.831
15.0	1.616	62.8	1.840
20.1	1.636	71.1	1.896
24.65	1.657	79.8	1.962
30.3	1.678	81.2	1.962
34.3	1.698	87.2	2.012
39.3	1.722	92.6	2.062
44.4	1.745	98.1	2.121
49.6	1.769	102.1	2.188
		105.6	2.243

The specific volumes found by Lange are consistently greater than those of Dieterici, the differences increasing from about .6 per cent. at 0° C. to nearly three per cent. at 100° C. The Andréef values are about midway between the two.

Mosher[67] has suggested the following equation for specific volumes: $v = 3.7 - \log_{10}(134 - t)$

The accompanying diagram, Fig. 4, shows the principal experimental data and also Mosher's curve. It is obvious that the Mosher equation represents the average of the experimental data fairly well from 0° C. to 100° C. It is equally obvious that the trend of the curve is such as to make it unsafe to extrapolate much above the higher limit, particularly as the equation makes the specific volume infinite at the critical point.

The investigations of the *specific heat of liquid ammonia* have yielded the following results:

SPECIFIC HEAT OF LIQUID AMMONIA

Investigator.	Date.	Temperature, Degrees Centigrade.	Specific Heat.
v. Strombeck[68]	1890	30 to 62.	1.229
Ludeking and Starr[69]	1893	0 to 26.	.878
		26 to 46.	.894
Elleau and Ennis[70]	1898	0 to 23.	1.021
Drewes[71]	1903	−76.9	.737
		−14.85	0.707
		+11.8	.974
		20.7	1.088
		30.9	1.144
		41.4	1.165
		51.9	1.174
Wood[72]	1912	15 to 20.	1.094

[67] American Society of Mechanical Engineers, Dec. 1912.
[68] Jour. Franklin Inst., Vol. 130, p. 467; 1890.
[69] Sill. Am. Jour. Sci. (3), 45, p. 200; 1893.
[70] Jour. Franklin Inst., Vol. 145, p. 189, 280; 1898.
[71] Dissertation, Hanover, 1903.
[72] Ice and Refrigeration, p. 123; 1912.

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In addition to the above, Dieterici,[73] from his own experiments, finds that the specific heat of liquid ammonia between 0° and 70° C. can be represented by

$$c = 1.118 + .00208t$$

with an error not exceeding one per cent. This agrees with v. Strombeck's results with the same degree of accuracy. There is not, however, sufficient evidence to give confidence in any of the determinations.

The best table of the properties of saturated ammonia that has been published so far is probably that given by Wobsa in his second paper. It is based upon his own vapor-pressure and characteristic equations. It leads to the following value of the entropy of saturated and superheated vapor:

$$N = 0.49 \log_e T - AR \log_e P - \frac{11.5}{T^3} . P - 0.38$$

and to the total heat:

$$H = 0.49.t - \frac{17.22}{T^2} . P + 0.188 \log_e P + 0.0000176P + 307.85$$

This equation simplifies to

$$H = 0.49.t - \left\{ \frac{17.22}{T^2} - 0.0000178 \right\} . P + 309.6$$

For the specific heat of superheated vapor we have

$$C_p = 0.500 + 0.00031.t + \frac{34.5}{T^3} (P - 10300).$$

The above equations are in metric and Centigrade units. For the specific heat and specific volume of the liquid, Dieterici's values are used.

Wobsa's table has been transformed into English units and is given herewith. It should not be confused with the earlier table by the same authority.

[73] Zeit. f. d. ges. Kälte Industrie: 11, p. 21; 1904.

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TABLE OF THE PROPERTIES OF SATURATED AMMONIA VAPOR BASED ON WOBSA'S SECOND EQUATION

Temperature, Degrees Fahrenheit	Pressure, Pounds per Square Inch, Abs.	Specific Volume of the Liquid, Cubic Feet per Pound	Specific Volume of the Vapor, Cubic Feet per Pound	Density, Pounds per Cubic Foot	Heat of the Liquid, B.t.u.	Total Heat, B.t.u.	Latent Heat, B.t.u. Total	Latent Heat, B.t.u. Internal	Latent Heat, B.t.u. External	Entropy. Liquid n	Entropy. Vapor N	Entropy. Difference N — n
—22	16.98	.02368	15.80	.06329	—58.91	524.8	583.7	534.2	49.50	—.1265	1.2090	1.3355
—21	17.46	.02370	15.41	.06489	—57.84	525.2	583.0	533.4	49.58	—.1241	1.2068	1.3309
—20	17.95	.02372	15.03	.06653	—56.77	525.5	582.3	532.6	49.65	—.1217	1.2046	1.3263
—19	18.44	.02374	14.66	.06821	—55.71	525.8	581.6	531.9	49.73	—.1193	1.2023	1.3216
—18	18.93	.02377	14.30	.06993	—54.64	526.2	580.9	531.1	49.80	—.1169	1.2001	1.3170
—17	19.43	.02379	13.95	.07168	—53.57	526.6	580.2	530.3	49.88	—.1145	1.1979	1.3124
—16	19.93	.02381	13.61	.07348	—52.51	527.0	579.5	529.5	49.95	—.1121	1.1957	1.3078
—15	20.45	.02384	13.27	.07536	—51.45	527.3	578.8	528.8	50.03	—.1097	1.1935	1.3032
—14	21.00	.02386	12.93	.07734	—50.39	527.7	578.1	528.0	50.10	—.1072	1.1912	1.2984
—13	21.58	.02389	12.60	.07937	—49.32	528.1	577.4	527.2	50.18	—.1048	1.1891	1.2939
—12	22.17	.02391	12.28	.08143	—48.25	528.4	576.7	526.4	50.25	—.1024	1.1870	1.2894
—11	22.76	.02394	11.97	.08354	—47.17	528.7	575.9	525.6	50.31	—.1001	1.1848	1.2849
—10	23.36	.02396	11.69	.08554	—46.10	529.1	575.2	524.8	50.38	—.0977	1.1827	1.2804
—9	24.56	.02398	11.41	.08764	—45.02	529.4	574.4	524.0	50.44	—.0954	1.1806	1.2760
—8	24.96	.02401	11.13	.08985	—43.95	529.7	573.7	523.2	50.51	—.0930	1.1785	1.2715
—7	25.18	.02403	10.86	.09208	—42.87	530.1	572.9	522.3	50.58	—.0906	1.1763	1.2669
—6	25.81	.02405	10.61	.09425	—41.80	530.4	572.2	521.6	50.64	—.0883	1.1742	1.2625
—5	26.46	.02408	10.37	.09643	—40.73	530.6	571.4	520.7	50.71	—.0859	1.1721	1.2580
—4	27.14	.02411	10.13	.09872	—39.65	530.9	570.6	519.8	50.78	—.0835	1.1699	1.2534
—3	27.83	.02413	9.90	.1010	—38.57	531.3	569.9	519.0	50.84	—.0811	1.1680	1.2491
—2	28.53	.02416	9.68	.1033	—37.48	531.6	569.1	518.2	50.90	—.0788	1.1660	1.2448
—1	29.23	.02418	9.48	.1055	—36.40	532.0	568.4	517.4	50.97	—.0764	1.1641	1.2405
0	29.95	.02420	9.28	.1078	—35.32	532.3	567.6	516.6	51.03	—.0740	1.1621	1.2361
1	30.68	.02422	9.08	.1101	—34.24	532.7	566.9	515.8	51.09	—.0717	1.1602	1.2319
2	31.42	.02425	8.89	.1125	—33.15	532.9	566.1	514.9	51.15	—.0693	1.1582	1.2275
3	32.19	.02427	8.70	.1149	—32.07	533.2	565.3	514.0	51.21	—.0670	1.1563	1.2233
4	32.98	.02430	8.51	.1175	—30.99	533.5	564.5	513.2	51.27	—.0646	1.1543	1.2189
5	33.81	.02433	8.32	.1202	—29.90	533.8	563.7	512.4	51.34	—.0622	1.1524	1.2146
6	34.65	.02436	8.13	.1230	—28.81	534.1	562.9	511.5	51.40	—.0599	1.1505	1.2104
7	35.49	.02439	7.95	.1258	—27.71	534.4	562.1	510.6	51.45	—.0576	1.1486	1.2062
8	36.34	.02442	7.77	.1288	—26.62	534.6	561.2	509.7	51.51	—.0553	1.1466	1.2019
9	37.19	.02444	7.59	.1318	—25.52	534.9	560.4	508.8	51.57	—.0530	1.1447	1.1977
10	38.05	.02447	7.42	.1348	—24.42	535.1	559.5	507.9	51.62	—.0507	1.1428	1.1935
11	38.94	.02450	7.25	.1379	—23.33	535.4	558.7	507.0	51.68	—.0483	1.1409	1.1892
12	39.84	.02452	7.08	.1412	—22.24	535.7	557.9	506.2	51.73	—.0460	1.1390	1.1850
13	40.76	.02455	6.91	.1447	—21.14	535.9	557.0	505.2	51.78	—.0437	1.1370	1.1807
14	41.69	.02458	6.75	.1482	—20.04	536.2	556.2	504.3	51.84	—.0414	1.1351	1.1765
15	42.64	.02460	6.59	.1517	—18.93	536.4	555.3	503.4	51.89	—.0391	1.1331	1.1722
16	43.60	.02463	6.44	.1553	—17.82	536.7	554.5	502.5	51.93	—.0368	1.1312	1.1680
17	44.60	.02466	6.30	.1587	—16.71	537.0	553.7	501.7	51.98	—.0345	1.1292	1.1637
18	45.62	.02469	6.17	.1621	—15.60	537.2	552.8	500.8	52.03	—.0322	1.1272	1.1594
19	46.65	.02472	6.05	.1653	—14.50	537.5	552.0	499.9	52.07	—.0299	1.1253	1.1552
20	47.70	.02474	5.93	.1686	—13.39	537.7	551.1	499.0	52.11	—.0275	1.1233	1.1508
21	48.77	.02477	5.81	.1721	—12.28	538.0	550.3	498.1	52.16	—.0252	1.1213	1.1465
22	49.85	.02480	5.69	.1756	—11.17	538.3	549.5	497.3	52.21	—.0229	1.1193	1.1422
23	50.95	.02483	5.57	.1795	—10.06	538.5	548.6	496.3	52.25	—.0206	1.1174	1.1380
24	52.06	.02485	5.47	.1828	—8.94	538.8	547.8	495.4	52.29	—.0183	1.1156	1.1339
25	53.19	.02488	5.36	.1866	—7.82	539.1	546.9	494	52.33	—.0160	1.1138	1.1298
26	54.36	.02491	5.25	.1905	—6.71	539.3	546.0	493.6	52.38	—.0138	1.1120	1.1258
27	55.5	.02494	5.14	.1946	—5.59	539.5	545.1	492.7	52.42	—.0115	1.1102	1.1217
28	56.7	.02497	5.04	.1984	—4.47	539.7	544.2	491.7	52.46	—.0092	1.1084	1.1176
29	57.9	.02500	4.94	.2024	—3.35	540.0	543.4	490.9	52.50	—.0069	1.1065	1.1134
30	59.1	.02502	4.84	.2066	—2.23	540.3	542.5	489.9	52.55	—.0046	1.1047	1.1093
31	60.4	.02505	4.74	.2110	—1.12	540.5	541.6	489.0	52.59	—.0023	1.1029	1.1052
32	61.7	.02508	4.64	.2155	0.00	540.7	540.7	488.1	52.63	0.0000	1.1011	1.1011

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TABLE OF THE PROPERTIES OF SATURATED AMMONIA VAPOR BASED ON WORSA'S SECOND EQUATION—*Continued*

Temperature, Degrees Fahrenheit	Pressure, Pounds per Square Inch, Abs.	Specific Volume of the Liquid, Cubic Feet per Pound	Specific Volume of the Vapor, Cubic Feet per Pound	Density, Pounds per Cubic Foot	Heat of the Liquid, B.t.u.	Total Heat, B.t.u.	Latent Heat, B.t.u.			Entropy.		
							Total	Internal	External	Liquid n	Vapor N	Difference N — n
33	63.0	.02511	4.54	.2203	1.13	540.9	539.8	487.1	52.67	.0023	1.0993	1.0970
34	64.3	.02513	4.46	.2242	2.26	541.2	538.9	486.2	52.71	.0046	1.0975	1.0929
35	65.7	.02516	4.37	.2288	3.39	541.4	538.0	485.2	52.75	.0069	1.0957	1.0888
36	67.1	.02519	4.29	.2331	4.52	541.6	537.1	484.3	52.79	.0091	1.0939	1.0848
37	68.5	.02522	4.21	.2375	5.65	541.9	536.2	483.4	52.83	.0114	1.0921	1.0807
38	69.9	.02525	4.13	.2421	6.78	542.1	535.3	482.4	52.87	.0136	1.0903	1.0767
39	71.3	.02528	4.05	.2469	7.91	542.2	534.3	481.4	52.9	.0159	1.0885	1.0726
40	72.7	.02531	3.97	.2519	9.04	542.4	533.4	480.5	52.94	.0182	1.0867	1.0685
41	74.1	.02534	3.89	.2571	10.17	542.7	532.5	479.5	52.97	.0205	1.0849	1.0644
42	75.6	.02537	3.82	.2618	11.31	542.8	531.5	478.5	53.01	.0227	1.0831	1.0604
43	77.1	.02540	3.75	.2667	12.45	543.0	530.5	477.5	53.04	.0249	1.0814	1.0565
44	78.6	.02543	3.68	.2718	13.60	543.2	529.6	476.5	53.07	.0272	1.0796	1.0524
45	80.2	.02546	3.61	.2770	14.75	543.4	528.6	475.6	53.01	.0294	1.0778	1.0484
46	81.8	.02549	3.54	.2825	15.88	543.5	527.6	474.5	53.13	.0316	1.0761	1.0445
47	83.4	.02552	3.47	.2882	17.02	543.6	526.6	473.4	53.15	.0338	1.0743	1.0405
48	85.1	.02555	3.40	.2941	18.16	543.8	525.6	472.4	53.18	.0360	1.0726	1.0366
49	86.8	.02558	3.34	.2994	19.30	543.9	524.6	471.4	53.20	.0383	1.0708	1.0325
50	88.5	.02561	3.28	.3049	20.45	544.1	523.6	470.4	53.22	.0405	1.0690	1.0285
51	90.2	.02564	3.22	.3106	21.60	544.2	522.6	469.4	53.24	.0427	1.0673	1.0246
52	92.0	.02567	3.16	.3165	22.76	544.3	521.5	468.2	53.27	.0450	1.0657	1.0207
53	93.8	.02570	3.10	.3226	23.91	544.4	520.5	467.2	53.29	.0472	1.0640	1.0168
54	95.6	.02573	3.04	.3289	25.06	544.6	519.5	466.2	53.31	.0495	1.0624	1.0129
55	97.4	.02576	2.98	.3356	26.22	544.7	518.5	465.2	53.32	.0517	1.0607	1.0090
56	99.2	.02579	2.93	.3413	27.37	544.9	517.5	464.2	53.34	.0539	1.0590	1.0051
57	101.0	.02582	2.88	.3472	28.52	545.0	516.5	463.1	53.36	.0562	1.0574	1.0012
58	102.9	.02585	2.83	.3534	29.67	545.2	515.5	462.1	53.38	.0584	1.0557	.9973
59	104.8	.02589	2.78	.3597	30.83	545.3	514.5	461.1	53.39	.0607	1.0540	.9933
60	106.7	.02592	2.73	.3663	31.99	545.4	513.4	460.0	53.41	.0629	1.0524	.9895
61	108.6	.02595	2.68	.3731	33.16	545.6	512.4	459.0	53.42	.0651	1.0507	.9856
62	110.6	.02599	2.63	.3802	34.32	545.7	511.4	458.0	53.43	.0673	1.0491	.9818
63	112.6	.02602	2.58	.3876	35.49	545.8	510.3	456.9	53.44	.0695	1.0474	.9779
64	114.7	.02605	2.53	.3953	36.65	546.0	509.3	455.8	53.45	.0717	1.0458	.9741
65	116.9	.02608	2.49	.4016	37.81	546.1	508.3	454.8	53.46	.0739	1.0441	.9702
66	119.1	.02611	2.45	.4082	38.98	546.2	507.2	453.7	53.47	.0761	1.0424	.9663
67	121.3	.02615	2.41	.4149	40.14	546.3	506.2	452.7	53.48	.0783	1.0408	.9625
68	123.5	.02618	2.37	.4218	41.31	546.4	505.1	451.6	53.49	.0805	1.0392	.9587
69	125.7	.02622	2.33	.4292	42.49	546.5	504.0	450.5	53.50	.0827	1.0376	.9549
70	127.9	.02625	2.29	.4367	43.66	546.6	502.9	449.4	53.50	.0849	1.0359	.9510
71	130.3	.02629	2.25	.4444	44.84	546.6	501.8	448.3	53.51	.0871	1.0343	.9472
72	132.6	.02632	2.21	.4525	46.02	546.7	500.7	447.2	53.51	.0893	1.0327	.9434
73	134.9	.02636	2.17	.4608	47.20	546.8	499.6	446.1	53.51	.0915	1.0311	.9396
74	137.3	.02640	2.13	.4695	48.37	546.9	498.5	445.0	53.51	.0937	1.0294	.9357
75	139.7	.02643	2.10	.4762	49.55	547.0	497.4	443.9	53.51	.0959	1.0279	.9320
76	142.1	.02647	2.06	.4854	50.73	547.0	486.3	442.8	53.50	.0981	1.0262	.9281
77	144.5	.02651	2.027	.4933	51.91	547.1	495.2	441.7	53.50	.1003	1.0245	.9242
78	146.9	.02655	1.994	.5015	53.09	547.1	494.0	440.5	53.49	.1025	1.0229	.9204
79	149.3	.02659	1.961	.5099	54.27	547.2	492.9	439.4	53.49	.1046	1.0213	.9167
80	151.8	.02662	1.928	.5187	55.46	547.2	491.7	438.2	03.48	.1068	1.0197	.9129
81	154.4	.02666	1.896	.5274	56.64	547.3	490.6	437.1	53.48	.1089	1.0182	.9093
82	157.0	.02670	1.864	.5365	57.82	547.3	489.5	436.0	53.47	.1110	1.0166	.9056
83	159.7	.02674	1.833	.5456	59.00	547.3	488.3	434.8	53.46	.1132	1.0150	.9018
84	162.5	.02678	1.803	.5546	60.18	547.3	487.1	433.6	03.45	.1154	1.0134	.8980
85	165.3	.02682	1.774	.5637	61.37	547.4	486.0	432.6	53.44	.1175	1.0118	.8943
86	168.1	.02686	1.745	.5731	62.55	547.5	484.9	431.5	53.43	.1197	1.0102	.8905
87	170.9	.02690	1.717	.5824	63.76	547.6	483.8	430.4	53.42	.1219	1.0087	.8868

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TABLE OF THE PROPERTIES OF SATURATED AMMONIA VAPOR BASED ON WORSA'S SECOND EQUATION—*Continued*

Temperature, Degrees Fahrenheit.	Pressure, Pounds per Square Inch, Abs.	Specific Volume of the Liquid, Cubic Feet per Pound	Specific Volume of the Vapor, Cubic Feet per Pound	Density, Pounds per Cubic Foot	Heat of the Liquid, B.t.u.	Total Heat, B.t.u.	Latent Heat, B.t.u.			Entropy.		
							Total	Internal	External	Liquid n	Vapor N	Difference N — n
88	173.8	.02694	1.690	.5917	64.97	547.6	482.6	429.2	53.41	.1240	1.0071	.8831
89	176.6	.02698	1.663	.6013	66.17	547.6	481.4	428.0	53.41	.1262	1.0056	.8794
90	179.5	.02702	1.636	.6112	67.38	547.6	480.2	426.8	53.40	.1283	1.0040	.8757
91	182.4	.02706	1.610	.6211	68.59	547.6	479.0	425.6	53.39	.1305	1.0025	.8720
92	185.3	.02710	1.584	.6313	69.80	547.7	477.9	424.5	53.37	.1326	1.0009	.8683
93	188.3	.02714	1.559	.6414	71.01	547.7	476.7	423.4	53.36	.1348	.9994	.8646
94	191.3	.02718	1.534	.6519	72.21	547.7	475.5	422.2	53.35	.1370	.9979	.8609
95	194.4	.02722	1.509	.6627	73.41	547.7	474.3	421.0	53.34	.1392	.9963	.8571
96	197.5	.02726	1.484	.6739	74.64	547.7	473.1	419.8	53.32	.1412	.9948	.8536
97	200.7	.02730	1.460	.6849	75.84	547.7	471.9	418.6	53.31	.1434	.9933	.8499
98	203.9	.02734	1.437	.6959	77.07	547.7	470.6	417.3	53.29	.1455	.9917	.8462
99	207.2	.02739	1.415	.7067	78.29	547.7	469.4	416.2	53.28	.1477	.9902	.8425
100	210.5	.02743	1.393	.7179	79.51	547.7	468.1	414.9	53.26	.1498	.9887	.8389
101	213.8	.02747	1.371	.7294	80.72	547.7	466.9	413.7	53.25	.1519	.9872	.8353
102	217.2	.02751	1.350	.7407	81.95	547.7	465.7	412.5	53.23	.1540	.9857	.8317
103	220.6	.02755	1.329	.7524	83.16	547.7	464.5	411.4	53.21	.1562	.9841	.8279
104	224.0	.02760	1.309	.7639	84.37	547.7	463.3	410.2	53.19	.1584	.9826	.8242
105	227.5	.02764	1.290	.7752	85.59	547.7	462.1	408.9	53.17	.1606	.9811	.8205
106	230.8	.02769	1.271	.7868	86.81	547.7	460.8	407.6	53.15	.1627	.9796	.8169
107	234.3	.02773	1.252	.7987	88.04	547.7	459.6	406.4	53.13	.1649	.9781	.8132
108	238.0	.02777	1.233	.8110	89.26	547.6	458.3	405.2	53.11	.1670	.9766	.8096
109	241.6	.02782	1.214	.8237	90.48	547.6	457.1	404.0	53.09	.1691	.9751	.8060
110	245.3	.02786	1.196	.8361	91.70	547.6	455.9	402.8	53.05	.1712	.9736	.8024
111	249.0	.02790	1.178	.8489	92.92	547.5	454.6	401.6	53.03	.1733	.9721	.7988
112	252.8	.02794	1.161	.8613	94.15	547.5	453.3	400.3	53.01	.1755	.9706	.7952
113	256.6	.02799	1.144	.8741	95.38	547.5	452.0	399.0	52.98	.1776	.9692	.7916
114	260.4	.02803	1.128	.8865	96.61	547.4	450.7	397.7	52.95	.1797	.9677	.7880
115	264.2	.02807	1.111	.9001	97.85	547.4	449.5	396.5	52.92	.1818	.9662	.7844
116	268.1	.02812	1.095	.9132	99.10	547.3	448.2	395.3	52.89	.1839	.9647	.7808
117	272.1	.02817	1.078	.9276	100.34	547.2	446.9	394.0	52.86	.1860	.9632	.7772
118	276.2	.02821	1.061	.9425	101.58	547.2	445.6	392.8	52.83	.1881	.9617	.7736
119	280.3	.02825	1.046	.9560	102.82	547.1	444.3	391.2	52.80	.1902	.9602	.7700
120	284.5	.02830	1.031	.9699	103.06	547.0	442.9	390.1	52.76	.1923	.9587	.7664
121	288.6	.02834	1.016	.9843	105.30	547.9	441.6	388.9	52.73	.1944	.9572	.7628
122	292.7	.02839	1.000	1.000	106.55	546.8	440.2	387.5	52.69	.1965	.9557	.7592
123	296.9	.02844	.985	1.015	107.81	546.7	438.9	386.3	52.66	.1986	.9542	.7556
124	301.2	.02849	.970	1.031	109.07	546.6	437.5	384.9	52.62	.2007	.9528	.7521
125	305.5	.02853	.956	1.046	110.33	546.5	436.2	383.6	52.58	.2028	.9513	.7485
126	309.9	.02858	.942	1.061	111.58	546.4	434.8	382.3	52.54	.2049	.9499	.7450
127	314.3	.02863	.929	1.076	112.83	546.3	433.5	381.0	52.50	.2070	.9484	.7414
128	318.8	.02868	.916	1.091	114.07	545.2	432.1	379.6	52.46	.2091	.9469	.7378
129	323.3	.02872	.904	1.106	115.32	546.0	430.7	378.3	52.42	.2112	.9455	.7343
130	327.9	.02877	.891	1.122	116.58	545.9	429.3	376.9	52.38	.2133	.9440	.7307
131	332.5	.02882	.878	1.139	117.82	545.8	428.0	375.7	52.34	.2154	.9426	.7272

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In conclusion, it may be said that the present state of our knowledge of the properties of ammonia is very much more satisfactory than it was ten years ago, and that the table given above may be used for ordinary engineering calculations with some confidence.

For greater accuracy, it is necessary that the specific heat of the liquid ammonia should be further investigated and that confirmatory data should be obtained on specific volumes of the saturated and superheated vapor. The vapor pressure needs some further determinations at low temperatures, but it is probably known with sufficient accuracy throughout the range used in engineering practice. It is also desirable to investigate further, at various pressures, the specific heat of the superheated vapor.

DISCUSSION.

Henry Torrance, Jr.—What is the pressure corresponding to zero temperature in your table?

Lionel S. Marks.—I'm afraid I haven't got that in my head. It can be interpolated without any difficulty. The table is directly converted from the Wobsa's table and, if desirable, it can be extended and intermediate points can be interpolated.

Henry Torrance, Jr.—I have tried to interpolate the pressure at zero temperature. I find it comes to 15.4 pounds, whereas the old table gave 15.67 pounds; that's pretty close.

President Shipley.—We will have to assume that.

John E. Starr.—I think our Society is greatly indebted to Professor Marks for really the first authoritative utterance that has been made before this Society on this rather vexed question on the properties of ammonia. I wish to call your attention to a single example. Probably the majority of us have been using the Wood tables, as extended for each degree, by George Davidson. Many of us are probably interested as much in the value of the latent heat of ammonia at zero or at a pressure of about 15 pounds as at any other point. If you will interpolate Wobsa's table you will find that the total latent heat at zero is 567.5. Now, I happen to remember that the latent heat at zero as given by Wood and extended by Davidson is 555.5. You will see what this means in this single item, in making calculations. There is a difference here in the latent heat of some 4 or 5 per cent. This table that Professor Marks has recommended as being the most accurate varies at that single point somewhere in the neighborhood of 12 B. t. u. per pound.

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President Shipley.—That is not 4 per cent. (Exact, 2.2.)

John E. Starr.—Well, I had not figured it up exactly; say 3 per cent. or whatever it is; but the point is this, Mr. President, that while, as a practical matter to an engineer, the differences in these tables do not amount to very much, when you come to figuring out the size of a compressor, or try to figure out the work done theoretically from displacement, latent heat, etc., and see how near you will get to your actual results, undoubtedly any of these tables, if used, would come well within the limits of error of any test. But there is this point, that, I think, is important, that no matter what the exact facts may be from a physicist's standpoint on these tables, we, as engineers, should agree to use one table, so that one man will not pick up Wood's table, another man Zeuner's table, another man Wobsa's table, and another man somebody else's table, with the result that, when we get through, our figures may not be very far apart, but still are not consistent with each other. I want to say also that the Bureau of Standards of the United States Government has taken up this matter. Members of this Society and members of the American Association of Refrigeration, about the same thing as far as membership is concerned, have secured an appropriation of $15,000 for this year, and expect to secure a continuing appropriation of $15,000 for each succeeding year, to be used by the Bureau of Standards in determining exactly these points which Professor Marks has laid before you, that is, to get exact experimental determination on all of these questions, from which can be constructed an authoritative table.

In the meantime, it seems to me that we are going to be more or less at sea so long as we all use different tables. In the case of carbon dioxide the greatest difference is 32 per cent. Now, that is too much. If you use Schröter's table in designing a machine, in one case, and use Amagat's table in another case, at a condensing temperature of about 70 degrees, and, if I remember rightly, a refrigerating temperature of about zero, you would have a compressor 32 per cent. larger in one case than in the other. But that is a different story from ammonia. Then, again, the case of the latent heat of ice. It does not make very much difference, practically, whether it is 142 or 144, but why not use either the one or the other until the question is authoritatively determined?

President Shipley.—I am sure we are very much indebted to Professor Marks for this paper. It is one of the things we have been pounding at, and it is a step in the right direction, the direction it

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will be necessary for all of us to go, and such men as he are the fellows we have got to look to for this sort of information. We cannot sit up nights and figure out these constants, get up equations and one thing and another. We have labor equations to work out. That's what we are chasing.

Henry Torrance, Jr.—A table of solutions of ammonia would be very interesting.

President Shipley.—Mr. Starr might tell you something about that. We have been working at that a couple of years down at our place; hence I think that would be very interesting.

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No. 108

PROPERTIES OF SATURATED AND SUPERHEATED AMMONIA

By William E. Mosher, Urbana, Ill.

(Non-Member of the Society.)

The vapor of anhydrous ammonia first became of interest in the field of mechanical engineering with the advent of Carré's absorption and Linde's compression refrigerating machines. With the development of the refrigeration industry this vapor has become more and more important and an accurate knowledge of its properties is highly desirable.

2 As in the case of steam and many other vapors, the first reliable experimental knowledge of the properties of ammonia was derived from the work of Regnault. He determined experimentally the relation between the pressure and the temperature of the saturated vapor and expressed it by means of empirical formulæ. He also determined the relative volumes of the superheated vapor at different pressures along an isothermal for the temperature 8.1 deg. cent., the specific heat, the theoretical density and the experimental density of the gas. The determinations made by Regnault of the specific heat of the liquid and the latent heat of vaporization were lost in the reign of the Commune, in 1871; twelve of the determinations of the latter magnitude, however, have been found.

3 The tables now used most extensively in refrigeration work and included in most handbooks on refrigeration are those of Wood, based upon Regnault's experiments. Peabody's tables, which appeared at about the same time, were based upon the work of Ledoux and upon the same form of equation of state, namely, that derived by Zeuner and applied to ammonia by Ledoux. Since these tables were published the properties of ammonia have been made the subject of considerable experimental work and various tables have been issued, although comparatively little is known of the subject even now when its importance in technical work is considered. Probably the most accurate table for the range covered is one recently calculated by Goodenough, although this was designed for class room purposes and is not based upon refined analysis.

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4 The present investigation was undertaken with the object of collecting and correlating the various scattered experimental data on the subject of the properties of ammonia. An attempt has been made to reconcile these data by means of well-known thermodynamic laws and principles so that the results may be consistent with each other; and to express the various properties by means of formulæ from which tables and charts in English units may be prepared. It is realized, however, that the experimental evidence is not as complete as could be desired and that more accurate experimental work may render necessary slight revision of the values of the constants in the equations here presented.

5 *Notation.* Throughout the investigation the absolute temperature of melting ice on the Fahrenheit scale has been taken as 491.64 deg., so that absolute zero is at —459.64 fahr. The value of 777.64 ft. lbs. has been used for the mechanical equivalent of heat. The notation used is as follows:

J = Joule's equivalent.
A = Reciprocal of same.
t = Temperature on the F. or the C. scale.
T = Absolute temperature.
p = Pressure.
v = Specific volume.
γ = Specific weight.
u = Intrinsic energy.
i = Heat content at constant pressure.
s = Entropy.
r = Latent heat of vaporization.
ρ = Internal heat.
Ψ = External latent heat = $Ap(v'' - v')$.
c = Specific heat.
c_p = Specific heat at constant pressure.
x = Quality of vapor mixture.
Subscript ^{k} indicates critical data.
$'$ indicates properties of liquid.
$''$ indicates properties of saturated vapor.

6 *Relation between Pressure and Temperature of Saturated Vapor.* To express the relation between the pressure and temperature of saturated vapors scores of formulæ have been proposed, some being of more or less rational form, involving empirical constants, but the greater number being purely empirical.

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a Biot's equation as used by Regnault has the form

$$\log p = a - b\alpha^n + c\beta^n$$

where $n = t - k$

The same formula was used in the computation of Peabody's tables.

b Wood used Rankine's formula in the form

$$\log p = a - \frac{b}{T}$$

with $a = 6.2495$ and $b = 2196$; limits, — 20 deg. fahr. to 100 deg. fahr.

c Goodenough used the Bertrand formula in the form

$$\log p = \log k - n \log \frac{T}{T - b}$$

with $\log k = 5.87395$, $n = 50$, $b = 84.3$.

7 It does not seem to be possible to find constants which will make equations of the above forms apply over more than a limited range of temperature, either with steam or with other vapors. An equation for steam has, however, recently been proposed by Marks[1], which is remarkable in that it gives pressures agreeing closely with experimental values throughout the range from 32 to 706.1 deg. fahr., the latter point being the critical temperature. This equation is based on the one used by van der Waals

$$\log \frac{p_k}{p} = a\left(\frac{T_k}{T} - 1\right) \qquad [1]$$

where p_k and T_k denote respectively the critical pressure and critical temperature. Instead of being a constant as used by van der Waals, a varies for different substances and for different temperatures with the same substance. Professor Marks found values of a at different temperatures for steam and then found an expression for its value in terms of the temperature and the critical temperature. By substituting this expression for a and the proper values for p_k and T_k in equation [1], he arrived at the following relation between the pressure and temperature of saturated steam

$$\log p = a - \frac{b}{T} - cT + eT^2 \qquad [2]$$

where

$a = 10.515354$
$b = 4873.71$
$c = 0.00405096$
$e = 0.000001392964$

[1] Trans. Am. Soc. M. E., vol. 33, 1911, p. 361.

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8 In the present investigation an attempt was made to use the above method to determine the pressure-temperature relation of ammonia. Several factors rendered the use of this method undesirable, among them being the sensitiveness of the method to changes in the critical data and the uncertainty of these data for ammonia, the lack of experimental data at temperatures near the critical point, and the large discrepancies existing in the data throughout the entire range. As will be seen later, however, this equation plays an important part in the present investigation.

9 Physicists have repeatedly attempted to find a relation between the pressures of different vapors at the same temperature such that a determination of the function $p = f(t)$ for one vapor would serve to determine this function for all other vapors. Ramsey and Young proposed the law

$$R = R' + k\,(T - T')$$

where R and R' are the ratios of the temperatures of two saturated vapors at two different pressures, and T and T' are the temperatures of one of the vapors corresponding to these pressures. They show that the law holds very closely for some 22 different substances arranged in 23 different pairs. In their paper they use the T and T' in the term $k\,(T - T')$ as being indiscriminately the numerators or the denominators of the ratios R and R'; i. e. they use the two equations

$$\frac{T_b}{T_a} = \frac{T'_b}{T'_a} + k'\,(T_a - T'_a) \qquad [3]$$

$$\frac{T_a}{T_b} = \frac{T'_a}{T'_b} + k\,(T_a - T'_a) \qquad [4]$$

without making any mention of the change from one form to the other and without recognizing that the two forms lead to different results.

10 This law has been corroborated by the work of Richardson and by the work of Ramsey and Travers on crypton, argon and xenon.

11 Ayrton and Perry, and Everett have each remarked upon the lack of symmetry of equation [3] and have shown that equation [4] is symmetrical. This is most clearly demonstrated by Moss, who shows that [3] may be thrown into the form

$$\frac{T_b}{T_a} = \left[\frac{T_b'}{T_a'} - k'T_a'\right] + k'T_a$$

and [4] may be thrown into the form

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$$\frac{T_a}{T_b} = \left[\frac{T_a'}{T_b'} - kT_a'\right] + kT_a$$

since T_a' and T_b' are the temperatures corresponding to some particular vapor pressure, these equations may be written respectively

$$\frac{T_b}{T_a} = k'T_a + c' \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

and

$$\frac{T_a}{T_b} = kT_a + c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6]$$

11a To test the symmetry of these equations they may be written respectively

$$\frac{T_a}{T_b} = \left(-\frac{k'}{c'}\right)\frac{T_a^2}{T_b} + \frac{1}{c'}$$

and

$$\frac{T_b}{T_a} = \left(-\frac{k}{c}\right)T_b + \frac{1}{c}$$

It is seen that if the left hand member of [5] is a linear function of the denominator its reciprocal will not be a linear function of the new denominator. On the other hand, if the left hand member of [6] is a linear function of the numerator, its reciprocal will also be a linear function of the new denominator.

12 Equation [6] may be written in the simple form

$$\frac{1}{T_b} = c\frac{1}{T_a} + k \ldots\ldots\ldots\ldots\ldots\ldots\ldots [7]$$

$\frac{1}{T_b}$ and $\frac{1}{T_a}$ thus being linear functions of each other.

13 Since equation [7] may be written

$$A - \frac{B}{T_b} = A' - \frac{B'}{T_a}$$

it follows that any equation to be applicable to all vapors in the same form with only its constants changed, and at the same time to be consistent with the temperature ratio law as stated above, must satisfy the condition that

$$p = f\left(A - \frac{B}{T}\right)$$

all other constants remaining the same for all vapors. Now, it happens that the equations which may be thrown into this form, such as the Rankine short form, the Roche equation, etc., do not satisfy the experimental data for steam throughout its range with

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the necessary degree of accuracy. On the other hand, the Marks equation, which does satisfy these data with remarkable accuracy throughout the complete range, cannot be thrown into the required form. In view of the various considerations mentioned it has been decided in the present investigation to accept the temperature ratio law as expressed in equation [7], to use water as the standard substance, to use the Marks equation, equation [2], as representing the pressure-temperature relation for water, and to make a step-by-step solution of the pressure-temperature relation for ammonia by means of these equations.

14 The method used in applying the temperature ratio law and in determining the value of the constants c and k in equation [7], is that used by Moss, who has applied it to 17 different vapors. A description of this method and of the construction of Fig. 1 is given in Appendix No. 1.

15 After plotting the points representing the experimental data the straight line shown in Fig. 1 was drawn in a manner such as to represent all the points in the best possible manner.

16 The effectiveness of any method that enables one to throw any given data into a form such that it may be represented by a straight line lies in the fact that it discloses immediately and strikingly any departure from the general trend and reveals unerringly points that depart from this trend. It enables one to give various observations their proper weight and it affords a much safer basis of extrapolation than can be obtained from curves. The case in hand illustrates this principle. If the points are plotted on the regular pt plane it is easily seen that no smooth curve such as represents a law of nature, could, if passed through Regnault's lower temperature points and Brill's lower points, at the same time pass through Brill's points in the region — 80 to — 30 deg. fahr. Further than this the chart discloses nothing, as an infinite number of curves could be drawn, giving different weights to the different points, or all points could be given equal weight and the equation could then be determined by least squares. An inspection of Fig. 1 shows, however, that the straight line which best represents the whole range represents very accurately Regnault's lower points, Brill's highest point and all of his points from — 80 to — 110 deg. fahr. In the range — 80 to — 30 deg. fahr. all of Brill's points lie above the line, as does Davies' — 41.8 deg. fahr. point. It is significant, however, that Davies' — 57.64 deg. fahr. point lies exactly on the line at precisely the point where Brill's points lie farthest from it.

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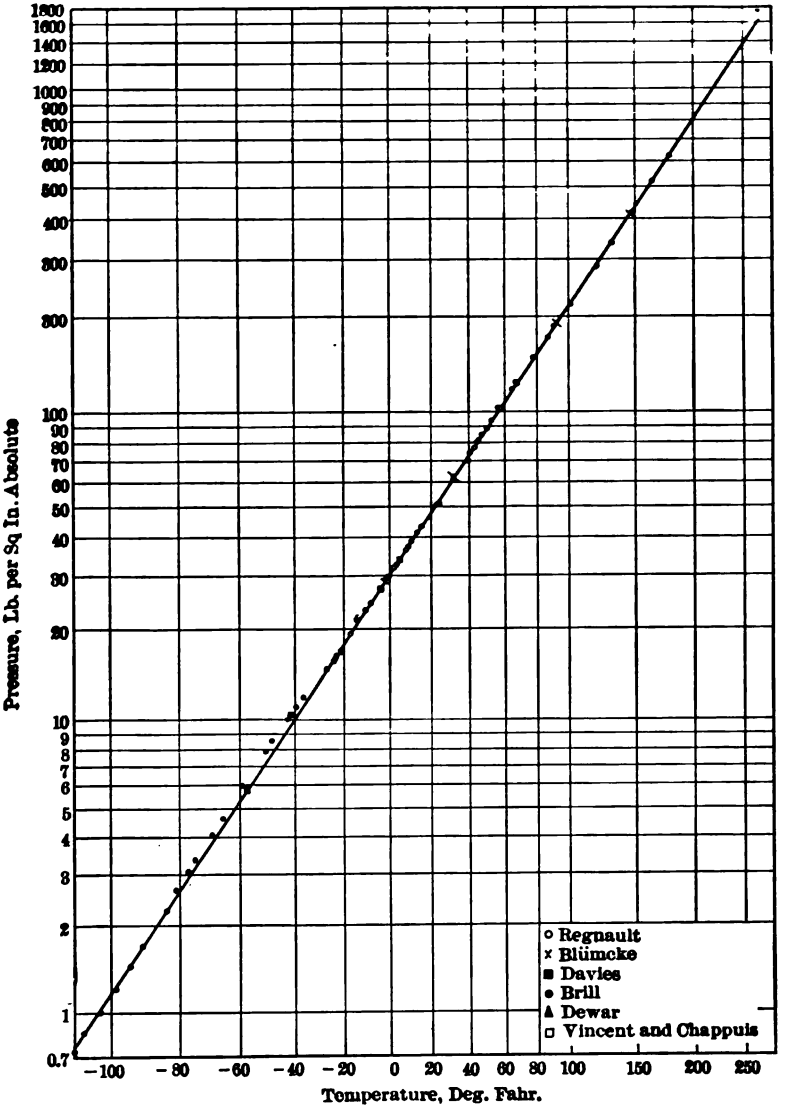

FIG. 1.—CURVE SHOWING AGREEMENT OF PRESSURES FOUND BY TEMPERATURE RATIO LAW WITH THOSE FOUND BY EXPERIMENT

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17 Through the range — 30 to + 100 deg. fahr. the line represents the experimental points very accurately; above 100 deg. fahr. Regnault's points lie slightly below the line. Now, all of Regnault's points above 100 deg. fahr. belong to his third series of experiments. In all of the higher pressure points of this series Regnault used a closed manometer and extensive corrections had to be applied to the height of mercury observed, and a comparison of the experiments in the range 40 to 90 deg. fahr. where the second and third series overlap shows that invariably the points determined in the third series by the use of the closed manometer lie below those determined in the second series by the use of the open manometer. The conclusion is evident that there was probably an error in the correction applied by Regnault to his readings with the closed manometer; the fact that these points lie below the line should therefore not be taken as conclusive evidence of the incorrectness of the line.

18 As to the critical data, it is seen that the points of both Dewar, and Vincent and Chappuis lie above the line. If the line be taken as correct this indicates either higher temperature, lower pressure, or both, at the critical point.

19 The same is the case with the dtermination of the critical data for water; as methods have been improved and greater precautions taken in the experimental work, the value found for the critical temperature has steadily risen until the latest determination, that of Holborn and Bauman, is 30 deg. higher than that found by Nadejdine 25 years earlier. It is reasonable to assume that the same errors may have been made in the ammonia determinations and that the true critical temperature of ammonia is higher than that found by either Dewar or Vincent or Chappuis. In the present investigation the critical data of ammonia are not of prime importance and the purely arbitrary assumption has been made, on the basis of the above reasoning and for want of better data, that the higher of the critical pressure determinations, that of Dewar, is correct. The corresponding temperature as determined by the temperature ratio law has been taken as the critical temperature. The resulting values are

$$p_k = 1690 \text{ lb. per sq. in.}$$
$$t_k = 273.2 \text{ deg. fahr.}$$

20 Since the above conclusions were drawn the articles giving the determinations of Jaquerod and Scheffer have been found. If plotted in Fig. 1 the point representing Jaquerod's determination falls below the straight line and that representing Scheffer's value

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falls almost exactly upon it. If Scheffer's value for the critical temperature is substituted in the temperature ratio law the resulting pressure is 1638.6 lb. per sq. in., while his experimental value is 1635.7 lb. per sq. in., the difference being about 1/6 of one per cent. These results offer corroboration of the correctness of the location of the straight line in Fig. 1, although the arbitrary values chosen for the critical temperature and pressure may be too high.

21 The equation of the straight line in Fig. 1 is

$$\frac{1}{T_a} = 1.70356 \frac{1}{T_w} - 0.0002242 \qquad [8]$$

In constructing tables with pressure as the argument the temperature of saturated steam at any pressure is found from steam tables. The corresponding saturation temperature of ammonia is then found by using equation [8] in the form

$$T_a = \frac{1}{\dfrac{1.70356}{T_w} - 0.0002242}$$

22 If temperature is taken as the argument the temperature at which steam will be saturated under the same pressure may be found by using equation [8] in the form

$$T_w = \frac{1}{\dfrac{0.587006}{T_a} + 0.0001316}$$

and the corresponding pressure is found from steam tables.

23 *Specific Volume of the Liquid.* There are available three sets of experimental data from which the specific volume of the liquid may be determined. Lange determined the density of liquid ammonia over the temperature range of —56 to +208 deg. fahr.; Dieterici, working by Young's method, obtained simultaneously the specific volumes of the liquid and of the saturated vapor over a temperature range of 32 to 222 fahr. In addition to these there are the specific gravity determinations of d'Andréeff, from which the specific volume may be calculated; these experiments cover the range of 14 to 68 deg. fahr.

24 In Fig. 2 the experimental values are plotted with specific volumes as ordinates, and temperatures as abscissae. The form of equation used to express the volume of the liquid in terms of the temperature is that used by Avenarius, or

$$v' = a - b \log (t_k - t) \qquad [9]$$

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The curve shown in Fig. 2 up to 160 deg. fahr. represents this equation with the constants as follows:

$$a = 0.06335$$
$$b = 0.016$$
$$t_k = 273.2$$

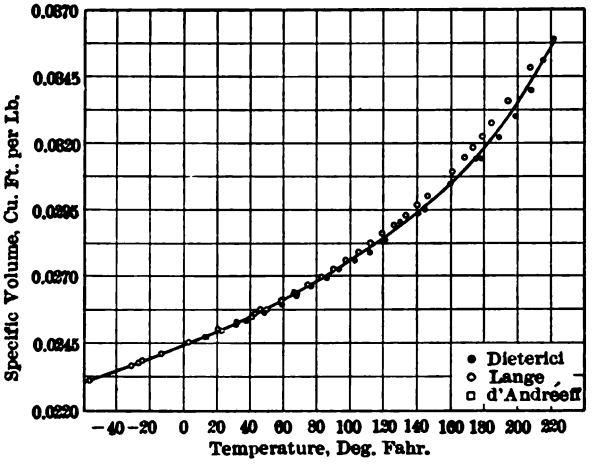

FIG. 2.—CURVE SHOWING AGREEMENT OF VOLUMES OF LIQUID AS CALCULATED WITH THOSE FOUND BY EXPERIMENT

25 In determining these constants the work of Dieterici was given the most weight, both because the methods he employed are superior to the others, and because the volumes of the vapor to be used with these values are those determined by Dieterici by the same method in the same series of experiments.

26 The part of the curve above 160 deg. fahr. represents the values found by the method discussed in Paragraphs 45 to 50.

27 *Latent Heat of Vaporization.* Since the experimental information regarding the latent heat of vaporization of ammonia is too meager to be used as a basis for the determination of the relation existing between it and the temperature of vaporization, this relationship will be determined from other considerations and the available data used as a check on the method.

28 Let [7] be differentiated with respect to the pressure. Then

$$\frac{-\dfrac{dT_s}{dp}}{T_s^2} = \frac{-c\dfrac{dT_w}{dp}}{T_w^2}$$

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which may be written

$$\frac{T_a \dfrac{dp}{dT_a}}{T_w \dfrac{dp}{dT_w}} = \frac{1}{c} \times \frac{T_w}{T_a}$$

or since

$$\frac{T_w}{T_a} = c + kT_w$$

there results

$$\frac{T_a \dfrac{dp}{dT_a}}{T_w \dfrac{dp}{dT_w}} = 1 + \left(\frac{k}{c}\right) T_w \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

Now by the Clapeyron relation connecting the latent heat and the absolute temperature of vaporization with the change of volume during vaporization

$$\left(\frac{v'' - v'}{r}\right) = \frac{1}{144.4T\left(\dfrac{dp}{dT}\right)_{sat}}$$

Substituting in equation [10]

$$\frac{\dfrac{(v'' - v')_w}{r_w}}{\dfrac{(v'' - v')_a}{r_a}} = 1 + \frac{k}{c} T_w \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

or with the proper values of the constants introduced

$$\frac{\dfrac{(v'' - v')_w}{r_w}}{\dfrac{(v'' - v')_a}{r_a}} = 1 - 0.0001316T_w \ldots\ldots\ldots\ldots [12]$$

29 The quantity $\dfrac{(v'' - v')_w}{r_w}$ may be found from steam tables or as follows: From the Clapeyron relation

$$\frac{(v'' - v')_w}{r_w} = \frac{1}{144.4T\left(\dfrac{dp}{dT_w}\right)_{sat}}$$

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By differentiating [2]

$$\left(\frac{dp}{dT_w}\right)_{sat} = p\left[\frac{11222.13}{T_w^2} + 0.00000641484\ T_w - 0.00932768\ T_w^2\right]$$

Substituting this value in the Clapeyron relation.

$$\frac{(v''-v')_w}{r_w} = \frac{1}{p\left[\frac{2078.07}{T_w} - 0.00172726\ T_w + 0.00000118787\ T_w^2\right]} \qquad [13]$$

30 By the use of equations [12] [13] $\frac{(v''-v')a}{r_a}$ may be calculated and if either numerator or denominator is known the other may be found. Fortunately there are available the experimental determinations of Dieterici of the specific volumes of the liquid and saturated vapor; the former were given in Pars. 23-26 and the latter will be discussed in Pars. 41-44. From these determinations various values of $(v''-v')$ were found and values of r calculated as described above.

31 According to the generally accepted ideas concerning the critical point, at that point $r = 0$ and $\frac{dr}{dt} = -\infty$. These facts led Thiesen to suggest as an empirical formula

$$r = c\ (t_k - t)^n$$

This form of equation has been used for water by Thiesen, Henning, and Marks and Davis, and for ammonia by Dieterici. When plotted on logarithmic cross-section paper it is represented by a straight line, the slope being equal to n.

32 The values of r found by the above method were plotted to the corresponding values of $(t_k - t)$ on logarithmic cross-section paper and were found to lie almost exactly on a straight line, indicating that the Thiesen formula might be used to express the desired relation. The formula may be written in the form

$$\log r = \log C + n \log (t_k - t)$$

and it was found that the values of the constants giving the best agreement with the plotted points are

$$\log C = 1.856064$$

and

$$n = 0.37$$

Therefore the final equation is

$$\log r = 1.856064 + 0.37 \log (273.2 - t) \ldots\ldots\ldots [14]$$

33 The available data concerning the latent heat of vaporization are given in Table 1 and the various points are plotted in Fig. 3, the

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TABLE 1. SUMMARY OF VARIOUS DETERMINATIONS OF THE LATENT HEAT OF VAPORIZATION.

Temperature, Deg. Cent.	Cal. per Kg.	Temperature, Deg. Fahr.	B. t. u.	Authority.
10.90	287.0	51.62	516.6	Regnault (Jacobus).
15.53	285.2	59.95	513.3	
16.00	290.5	60.80	522.8	
12.94	283.8	55.29	510.8	
11.90	285.8	53.42	514.4	
10.73	288.1	51.31	518.5	
11.04	292.5	51.87	526.4	
10.15	292.4	50.27	526.2	
9.52	295.0	49.14	531.0	
10.99	293.3	51.78	527.9	
12.60	291.6	54.68	524.8	
7.80	291.8	46.04	525.2	
7.80	294.2	46.04	529.5	Regnault (Dieterici).
11.00	291.3	51.80	524.3	
16.00	297.4	60.80	535.3	
19.53	296.5	67.15	533.7	Von Strombeck.
17.00	296.8	62.60	534.2	
—33.64	337.0	—28.55	606.6	Franklin and Kraus.
—33.40	321.3	—28.12	578.3	Estreicher and Schnerr.
.....	.....	84.6	524.8	Denton and Jacobus.
.....	.....	82.7	525.7	
.....	.....	87.7	512.4	
.....	.....	—10.7	569.2	
.....	.....	—3.2	603.5	
.....	.....	+14.5	570.4	

full line in this figure representing equation [14]. Of the determination of r made by Regnault, the greater number were lost, but 12 were saved and later published. The results of these experiments do not give r directly and have been variously interpreted by different writers. The table contains the interpretation of Jacobus and the three values of r as quoted from Regnault by Dieterici. Two values for r are given by von Strombeck, one being an average of 12 experiments, the other of eight. The value given by Franklin and Kraus is an average of three determinations at the normal boiling point, and the value obtained is exactly the value deduced by the same writers from the absolute boiling point and the molecular elevation. A different value was found at the normal boiling point by Estreicher and Schnerr. The values given by Denton and Jacobus, represented in Fig. 3 by crosses, were calculated from readings taken during a test of an ammonia compressor, and hence cannot be considered of much weight; because of the scarcity of scientific data, however, these points are included in the table and chart.

34 In Fig. 3 are also plotted the curves that represent various equations used in calculating the latent heat of vaporization, as given in the various existing tables. These are plotted exactly as given and it should be remembered that there is some variation in the value of the heat unit used by different writers; consequently the various curves are not exactly comparable and are given simply to

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show the variation in the values of latent heat as given in the tables now in use.

35 The equations of the curves shown in Fig. 3 are

Ledoux.....$r = 583.33 - 0.5499t - 0.0001173t^2$
Wood.....$r = 555.5 - 0.613t - 0.000219t^2$
Peabody.....$r = 540 - 0.8\ (t - 32)$
Dieterici.....$\log r = 1.56141 + 0.5 \log (266.9 - t)$
Goodenough.....$\log r = 1.7920 + 0.4 \log (266 - t)$

36 No comment is necessary regarding the curves for r according to Ledoux, Wood and Peabody, since their equations are not of a form such as to give correct results at high temperatures. Moreover they were derived before there were experimental determinations of the volume of the saturated vapor, from which latent heats could be calculated.

37 Dieterici used Zeuner's empirical expression for the second term of Regnault's pressure-temperature equation, and omitted the third term entirely. This approximation is quite accurate for low temperatures, but as the temperature increases the pressures thus calculated become too small, and this error increases rapidly at high temperatures. For instance, Regnault extrapolates his curve and gives for 212 deg. fahr. a pressure of 901 . 6 lb. per sq. in., while the value calculated by Dieterici for this temperature is 847.1 lb. per sq. in. or 6 per cent lower. As the error is increasing, the values of $\left(\frac{dp}{dt}\right)_{sat}$ are too small and values of r calculated by means of the Clapeyron equation are too small at high temperatures. Since the relation employed between r and $(t_k - t)$ is a straight line on logarithmic paper and the values of $\frac{dp}{dt}$, consequently of r, agree at some medium temperature, the values given by the equation at low temperatures will be too high. This is shown in Fig. 3, where it is seen that Dieterici's curve passes above the highest of the actual experimental determinations of r at —28 deg. fahr.

38 The equation used by Goodenough fits the actual determinations and is consistent with the Clausius relation, using Dieterici's values for volumes and Goodenough's constants in Bertrand's pressure-temperature equation. This latter equation, however, applies over but a small temperature range. The variation between Goodenough's r curve and the present one is due to the different pressure-temperature relation used and the higher value assumed for the critical temperature.

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39 It is believed that, due to the form of equation [14] and the accuracy with which it represents the derived values of r where known, the equation may be safely extrapolated as far as required in this investigation.

40 The comparison between the values of r given by equation [14], the corresponding values of v'' derived from the Clausius rela-

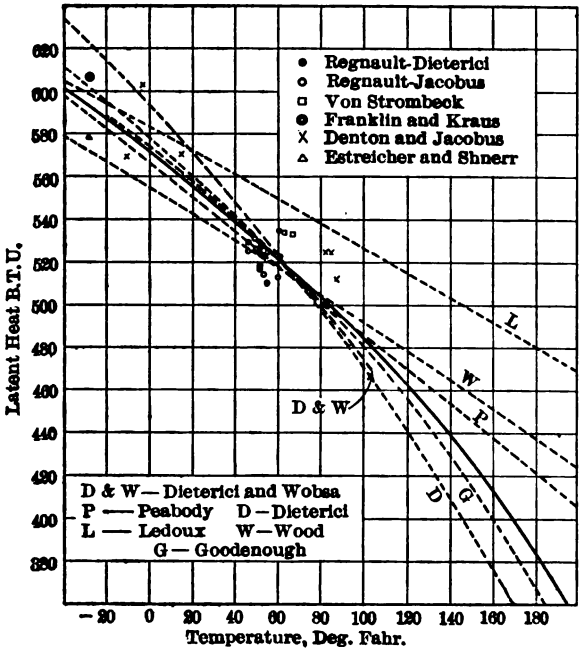

FIG. 3.—CURVES SHOWING COMPARISON OF EXPERIMENTAL VALUES FOR LATENT HEAT OF VAPORIZATION WITH VALUES AS CALCULATED BY VARIOUS WRITERS.

tion, and the experimental values for v'', properly belongs in the next section and is there shown.

41 *Specific Volume of Saturated Vapor.* The only available experimental determinations of the specific volume of the saturated vapor are those of Dieterici. These experiments extend up to a temperature of 222 deg. fahr., but unfortunately were not carried below a temperature of 32 deg. fahr. Owing to the form of the curve representing the volume-temperature relation, any extended extrapolation of the curve or of any empirical equation to represent this relation would be very unsafe below 32 deg. fahr., where the volume is seen to increase very rapidly.

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42 As shown in the preceding section, however, equation [14] is believed to be of a form such that extrapolation can be carried to very low temperatures. Therefore in the present investigation the volumes of the saturated vapor have been calculated as follows:

43 By the use of equations [12] and [13] values of $\frac{(v''-v')_a}{r_a}$ were calculated. These values multiplied by the corresponding values of r found from equation [14] gave the values of $(v''-v')$. The addition of the proper values of v' found from equation [9] gave the values of v'', the quantity desired.

44 The agreement of the values of v'' calculated by the above method is shown in Fig. 4, the curve in this figure representing the calculated values and the points the observed values.

45 *Specific Volume of Liquid and Saturated Vapor at High Temperatures.* The "law of the straight diameter" was first proposed by Cailletet and Mathias in 1886. This law, as originally given, stated that if the densities of a liquid and its saturated vapor are plotted (as abscissae) against the corresponding temperature (as ordinates) to form a dome, the mid-points of the horizontal chords of this dome will lie in a straight line nearly parallel to the axis of temperatures. References to the law may be found in an article by Davis[1].

TABLE 2. THE LAW OF THE STRAIGHT DIAMETER FOR AMMONIA.

Temperature. Deg. Fahr.	Density of Vapor.	Density of Liquid.	Mean Density.	By Formula.	Difference.
—40	0.0393	42.704	21.372	21.372	±0.000
—30	0.0517	42.296	21.174	21.174	±0.000
—20	0.0671	41.883	20.975	20 974	—0.001
—10	0.0860	41.461	20.774	20.774	±0.000
0	0.1088	41.039	20.574	20.572	—0.002
+10	0.1362	40.608	20.372	20.370	—0.002
20	0.1689	40.169	20.169	20.167	—0.002
30	0.2075	39.722	19.965	19.964	—0.001
40	0.2525	39.267	19.760	19.759	—0.001
50	0.3051	38.803	19.554	19.554	±0.000
60	0.3657	38.329	19.347	19.347	±0.000
70	0.4355	37.844	19.140	19.140	±0.000
80	0.5152	37.348	18.932	18.932	±0.000
90	0.6061	36.841	18.724	18.724	±0.000
100	0.7099	36.319	18.514	18.514	±0.000
110	0.8265	35.782	18.304	18.303	—0.001
120	0.9590	35.228	18.093	18.092	—0.001
130	1.1062	34.655	17.881	17.880	—0.001
140	1.2756	34.061	17.668	17.667	—0.001
150	1.4643	33.444	17.454	17.453	—0.001
160	1.6763	32.798	17.237	17.238	+0.001

46 It was found by Young that the diameter is actually straight in the case of all but a few substances, normal pentane being an

[1] Proc. Am. Acad. of Arts and Sciences, vol. 45, 1910, p. 305.

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example of this class. In the case of most substances, however, the diameter can be represented accurately by a second degree equation; some substances, such as alcohols, require a third degree equation.

47 In order to find the equation of the straight diameter for ammonia the values of the densities of the liquid and of the saturated

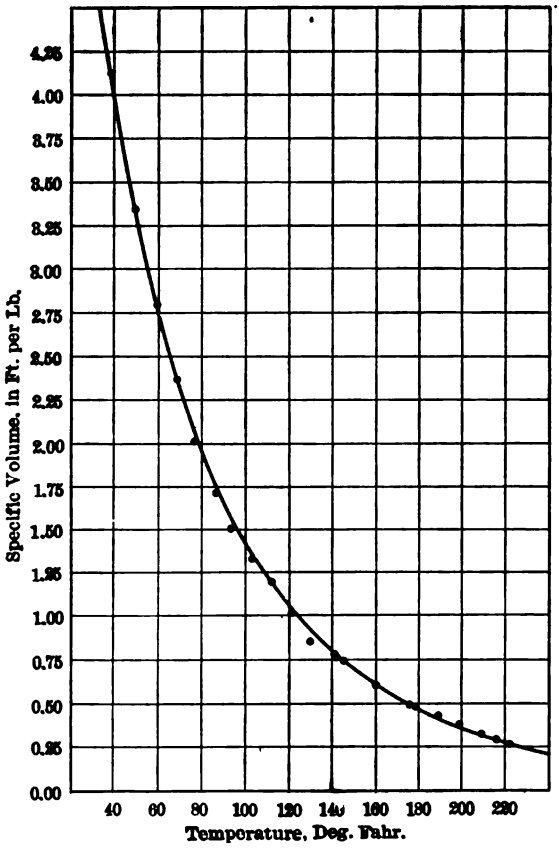

FIG. 4.—CURVE SHOWING AGREEMENT OF VOLUMES OF SATURATED VAPOR AS CALCULATED WITH THOSE FOUND EXPERIMENTALLY BY DIETERICI

vapor were found at 10 deg. intervals. The values for the liquid were calculated by the use of equation [9], and those for the vapor by the method described in Pars. 41-44. At each of the temperatures the mean density was calculated. The results are given in Table 2 and plotted in Fig. 5, where the points for the liquid and vapor are shown as large circles and the mean points as small circles.

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The diameter is seen to be slightly curved, but it may be accurately represented by the second degree equation

$$\gamma = 19.3473 - 0.02067\ (t - 60) - 0.0000042\ (t - 60)^2 \ldots . [15]$$

The table shows that this equation represents the mean densities as calculated by the other method with a maximum error of about 1/100 of one per cent over a temperature range of —40 to +160 deg. fahr.

48 The method used at ordinary temperatures for finding the change of volume on vaporization, or $(v'' - v')$, may be employed at temperatures up to the critical point if it is assumed that the values for r found by equation [14] are correct up to that point. Equation [15] gives values for

$$\frac{\gamma'' + \gamma'}{2} = \frac{1}{2}\left[\frac{1}{v''} + \frac{1}{v'}\right]$$

A simple algebraic manipulation gives

$$v'' = \frac{\gamma(v'' - v') + 1 + \sqrt{\gamma^2 (v'' - v')^2 + 1}}{2\gamma}$$

Having values for v'' and $(v'' - v')$, the values for v' may be easily found. This method enables the values of the volumes of the liquid and the saturated vapor to be found at least qualitatively up to the critical point itself.

49 Above 160 deg. fahr. the values found for v' by this method were materially lower than those found by equation [9] and that the difference increased as the temperature increased above this point. An inspection of equation [9] shows that this equation would give a value of $+\infty$ for the volume of the liquid at the critical point, whereas at this point the liquid has a finite volume. In the case of other vapors it has been shown that the form of the equation used, that of Avenarius, gives accurate values at temperatures somewhat removed from the critical point, but that it does not hold near this point. Therefore, in the present case equation [9] has been used only up to 160 deg. fahr., and the values above this temperature have been calculated by the law of the straight diameter.

50 Since the diameter is nearly parallel to the axis of temperatures a considerable error in the value of the critical temperature will cause but a small error in the resulting value of the critical density. The substitution in equation [15] of the assumed value of t_k, or 273.2 deg. fahr., gives for the critical density and volume respectively

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$\gamma_k = 14.75$ lb. per cu. ft.
$v_k = 0.0678$ cu. ft. per lb.

51 *Specific Volume of the Superheated Vapor.* The attempt has often been made to deduce rationally an equation of state which with suitable change of constants will represent the relation $f(P, v, T) = 0$ for various fluids in all states from the gaseous condition above the critical temperature to the liquid conditon. Such equations are constructed with special reference to the behavior of fluids in the neighborhood of the critical state and apply more particularly to fluids, the critical temperature of which is within the range encountered in practice. In the case of a fluid such as ammonia, however, the critical temperature of which is far above the

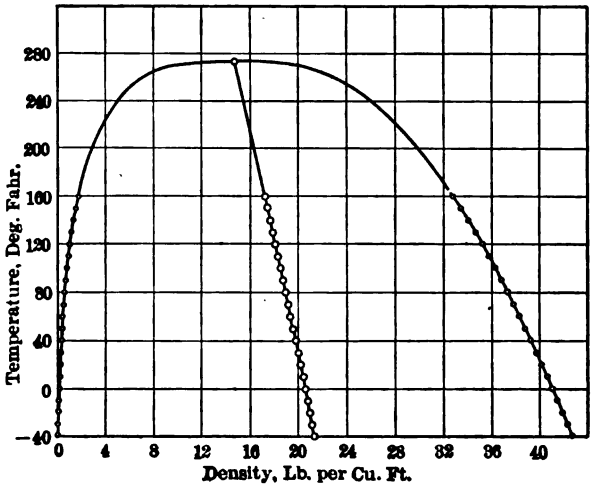

FIG. 5.—CURVE SHOWING DOME OF TEMPERATURE-DENSITY PLANE AND "STRAIGHT DIAMETER" OF CAILLETET AND MATHIAS

working range, purely empirical equations of simpler form give better results throughout the small range covered in practice, and in addition lend themselves much more readily to the formation of the various heat equations. Of these equations those of Ledoux, Zeuner, Peabody and Wood were based upon various doubtful assumptions, while Wobsa's first equation gives values that do not closely agree with experimental results, and only his second equation

$$v - a = \frac{BT}{p} - \frac{c}{T^n} + \frac{b}{p} \quad \text{[16]}$$

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with

$$B = 49.736$$
$$a = 0.0075$$
$$c = 2450$$
$$n = 2$$
$$b = 80$$

is quite satisfactory in this respect.

52 In choosing a characteristic equation several points must be considered.

a The equation must represent with fair accuracy the available reliable experimental data on the relations of p, v and T.

b The equation should be of a form such as to make the various thermodynamic relations derived from it as simple as possible.

c These derived equations must represent accurately the experimental data.

53 Wobsa's second equation fulfills the first of these conditions admirably. It is, however, somewhat defective with respect to the other requirements. The good results obtained from Goodenough's equation for superheated steam

$$v + c = \frac{BT}{p} - (1 + ap)\frac{m}{T^n} \quad \text{[17]}$$

suggested the adoption of the same form of equation for superheated ammonia in the preliminary investigation. This equation satisfies the second condition in that it gives derived relations of comparatively simple form. A trial with various sets of constants showed that it could be made to represent the volume measurements substantially with the same accuracy as Wobsa's second equation, and thereby satisfy the first condition. Having established the fact that the proposed equation is permissible, the next step was the determination of the constants. In connection with this process emphasis must be placed on the third consideration heretofore mentioned. From the characteristic equation are derived expressions for (*a*) the specific heat at constant pressure; (*b*) the heat content of the superheated and also of the saturated vapor; (*c*) the Joule-Thomson co-efficient. Hence the constants must be chosen not with reference to volume alone. While the volume measurements must be satisfied three other derived relations must conform equally well to the experimental data in the respective fields.

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54 With due consideration of all the conditions the following values were finally assumed for the constants:

$B = 0.6321$, p in lb. per sq. in.
$\log m = 12.900000$
$c = 0.100$
$n = 5$
$a = 0$

The final equation with constants inserted is therefore

$$v + 0.100 = 0.6321 \frac{T}{p} - \frac{79433 \times 10^8}{T^5} \quad \ldots\ldots\ldots\ldots [18]$$

55 It will be seen that the constant a is taken as zero. In view of the fact that the available data consist only of values along the saturation curve and in most cases but one point on each isotherm in the superheated region, no information is available regarding the shape or curvature of these isotherms on the $pv - p$ plane; moreover, the derived equations demand an exceedingly small value of a. The use of straight lines for these isotherms therefore seems to be as well justified as the use of parabolas; hence a was made equal to zero.

56 A summary of the various direct determinations of the specific volume of the superheated vapor according to Perman and Davies and LeDuc and Guye is given in Table 3. In Table 4 the values given by equation [18] and by Wobsa's first and second equations are compared with these experimental determinations. It is seen that both equation [18] and Wobsa's second equation give results agreeing better with experiment at the one atmosphere points than those obtained from Wobsa's first equation. At the 32, 122 and 212 deg. fahr. points at one atmosphere pressure equation [18] and Wobsa's second equation give practically the same percentage deviation from the experimental values. At —4 deg. Wobsa's second equation gives a better agreement with the experimental value than does equation [18]; this point, however, is considerably below the range found for superheated ammonia in practice, and it is believed that the considerations appearing in the discussion of the heat equations derived from the characteristic equation justify the use of equation [18] in preference to Wobsa's equations.

57 In Fig. 6 the isotherms deduced from equation [18] are drawn on the $pv - p$ plane and the various experimental points are plotted in order to show the agreement. From this chart it is seen that if both of the determinations of Perman and Davies at 32 deg.

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are correct, the one at one atmosphere and the other at one-half atmosphere, then either the saturation curve should lie considerably higher or the 32 deg. isotherm should be sharply curved. Since the

TABLE 3. SUMMARY OF VARIOUS DETERMINATIONS OF VOLUME OF THE SUPERHEATED VAPOR.

Pressure, Atmos.	Temperature, Deg. Cent.	Volume in Liters per Gram.	Temperature, Deg. Fahr.	Volume, Cu. Ft. per Lb.	Authority.
1/2	0	2.6096	32	41.8006	Perman
1	—20	1.19575	—4	19.1535	Perman
	0	1.2973	32	20.7802	Perman
	50	1.5473	122	24.7847	Perman
	100	1.7964	212	28.7747	Perman
	0	1.2955	32	20.7513	Le Duc
	0	1.2974	32	20.7818	Guye

TABLE 4. COMPARISON OF VALUES OBTAINED FROM VARIOUS EQUATIONS FOR VOLUME OF SUPERHEATED VAPOR WITH EXPERIMENTAL VALUES.

Pressure, Atmos.	Temperature, Deg. Fahr.	Experimental Values.		Computed from 18.		Computed by Wobsa I.		Computed by Wobsa II.	
		Authority.	Value.	Value.	% Diff. from Exp.	Value.	% Diff. from Exp.	Value.	% Diff. from Exp.
1	—4	Perman	19.154	19.093	—0.32	19.121	—0.17	19.140	—0.07
	32	Perman	20.780	20.769	—0.05	20.745	—0.17	20.767	—0.06
		Guye	20.782	20.769	—0.06	20.745	—0.18	20.767	—0.07
		Le Duc	20.751	20.769	+0.09	20.745	—0.03	20.767	+0.08
	122	Perman	24.785	24.798	+0.05	24.746	—0.16	24.775	—0.04
	212	Perman	28.775	28.730	—0.16	28.695	—0.28	28.725	—0.17
1/2	32	Perman	41.801	41.916	+0.23	41.821	+0.05	41.939	+0.33

one atmosphere determination agrees closely with the determinations of LeDuc and Guye, since there is good authority for the location of the saturation curve, and since the flatness of the isotherms is fairly well established, it would seem that the half atmosphere point of Perman and Davies is probably in error.

58 In Fig. 6 the full line curve represents values resulting from equation [18] and the dotted line curve represents the values resulting from equation [15]. A comparison of Wobsa's equations is not given because the constants in those equations were determined on the assumption of a different pressure-temperature relation along the saturation curve; the substitution in Wobsa's equations of the values of pressure corresponding to given temperatures as used in this investigation would not therefore give values of volume comparable with those deduced from equation [18]. It may be stated, however, that Wobsa's equations give very fair agreement with the

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values found experimentally by Dieterici, the maximum deviation of the second equation from the values given in Dieterici's table being a little over 2 per cent.

59 In addition to the preceding the only data available for the purpose of checking the characteristic equation are the results of a series of experiments performed by Regnault. In these experiments measurements were made of the relative volumes occupied by a quantity of ammonia gas at different pressures along the isotherm

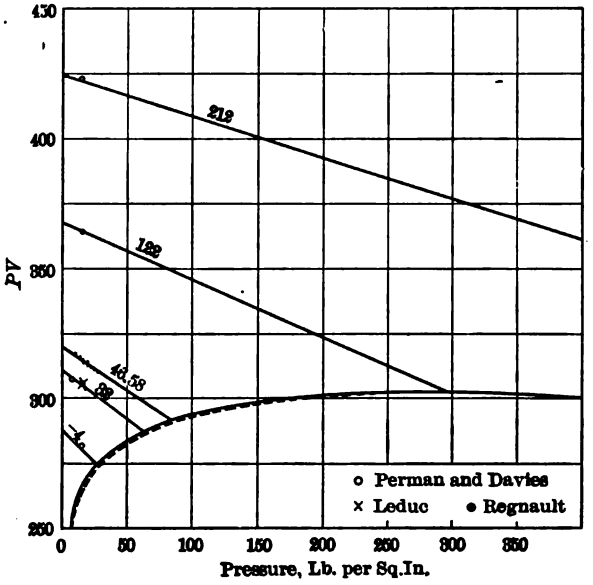

FIG. 6.—COMPARISON OF ISOTHERMS DEDUCED FROM EQUATION [18] WITH POINTS REPRESENTING EXPERIMENTAL DETERMINATIONS SHOWN ON PV — P PLANE

corresponding to a temperature of 8.1 deg. cent. or 46.58 deg. fahr. As the weight of ammonia used was not recorded, the experiments can only be used to obtain the relative values of the specific volume or of the product pv along this isotherm. In making use of these values the products pv were plotted against the corresponding values of p, both quantities being measured in the units employed by Regnault. A straight line was next passed through these points by the method of least squares. It was found that the pressure equivalent to 20 lb. per sq. in. came at about the center of the group of points, and the value of the specific volume was calculated by equation [18] for this pressure and a temperature of 46.58 deg. fahr.; this value

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multiplied by the pressure gave a value of the product pv in English units. The value of this product in the units used by Regnault was then found at the point where the straight line determined by least squares crossed the pressure coördinate equivalent to a pressure of 20 lb. per sq. in. From these two values for pv the conversion factor 0.00561 was found, this being the number by which Regnault's values of pv must be multiplied in order that the isotherm calculated from equation [18] shall pass through the center of Regnault's group of points. All of his values of pv were multiplied by this factor and the points plotted in Fig. 6 as small black dots. The only information they afford is a check on the slope of the isotherm for 46.58 deg. fahr. on the $pv - p$ plane. The points seem to indicate that the isotherms, near this temperature at least, are very flat curves or even straight lines.

60 *Specific Heat of the Superheated Vapor.* The first determination of the specific heat of superheated ammonia was made by Regnault, who found a value of 0.50836 at atmospheric pressure and over a temperature range of 75 deg. fahr. to 420 deg. fahr. Later Wiedemann performed two series of experiments at a pressure of about 16 lb. per sq. in.; he found a value of 0.5202 between 77 and 212 deg. fahr. and a value of 0.5356 between 77 and 392 deg. fahr. He proposed the equation

$$c_p = 0.4949 + 0.000172t$$

61 Thus far the history is much the same as in the case of superheated steam, the specific heat of which was long supposed to be independent of both temperature and pressure and equal to 0.48 as determined by Regnault; later the investigations of Maillard and LeChatelier and of Lange agreed in making it a linear function of the temperature. In the case of steam, however, the experiments of Knoblauch and Jakob, Thomas, and Knoblauch and Mollier have shown that the specific heat of superheated steam depends upon the pressure. While no experiments have been made to investigate the variation of the specific heat of superheated ammonia with pressure, it is very probable that there is such a variation and its rate may be determined by means of Clausius' thermodynamic relation providing a sufficiently accurate characteristic equation has been determined. The process of obtaining an explicit expression for c_p in terms of the variables p and T has inherent difficulties and is rendered more difficult in this case by the meagerness of the data available. The success with which the method has been applied to superheated steam

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by Goodenough, however, seems to warrant its use in the present investigation.

62 The application of the Clausius relation to equation [18] readily gives the following equation for c_p:

$$c_p = \phi\ (T) + \frac{Amn\ (n+1)}{T^{n+1}}\ p \ldots\ldots\ldots\ldots\ldots\ldots [19]$$

For the complete derivation of this equation see Appendix No. 2.

63 If the arbitrary function $\phi\ (T)$ can be determined, there will result an explicit expression for c_p in terms of the variables p and T. Wobsa has used the same method of analysis starting with his own characteristic equations and has obtained equations for c_p similar to the present one.

64 The determination of the proper function $\phi\ (T)$ is the critical point of the investigation. Wobsa equated his expression for c_p at atmospheric pressure to Wiedemann's linear equation for c_p at atmospheric pressure and thus found the $\phi\ (T)$ to be of the form

$$\phi\ (T) = a + bt - \frac{c}{T^3}$$

He shows that the terms in the third power of T, which is the correction term for atmospheric pressure, is vanishingly small above 212 deg. fahr. and that above this temperature c_p at infinitely small pressures will not differ from c_p at atmospheric pressure, or $\phi\ (T) = 0.4949 + 0.000172t$. Below 212 deg. fahr, where the correction term becomes appreciable, Wobsa substitutes the linear function $\phi\ (T) = 0.4712 + 0.000278t$.

65 For the determination of $\phi\ (T)$ in the present investigation there are available the recent determinations of c_p at high temperatures by Nernst. In addition to the results of his own work, Nernst gives a summary of the results of previous investigations (see Table 5). In this table the values are given as molecular specific heats and these have been converted into specific heats per unit of weight by

TABLE 5. SUMMARY OF Cp MEASUREMENTS AS GIVEN BY NERNST.

Temperature, Deg. Cent.	Molecular Cp.	Temperature, Deg. Fahr.	Cp.	Authority.
20	8.64	68	0.506	Keutel.
20	8.62	68	0.505	Voller.
25-100	8.84	77-212	0.518	E. Wiedemann.
25-200	9.11	77-392	0.534	E. Wiedemann.
24-216	8.71	75-421	0.510	Regnault.
365-567	10.4	689-1053	0.609	Nernst.
480-680	11.2	896-1256	0.656	Nernst.

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dividing by the molecular weight of NH_3 or 17.064. It is seen that the values given for Wiedemann are lower than those quoted earlier in this section from the original; while the value given for Regnault is higher than the original. As the original papers of Keutel and Voller are not at hand the values given in this table for their results are assumed to be correct, but the values used for Wiedemann and Regnault are those taken from the original.

66 If in the equation for c_p, $p = 0$, the equation reduces to $c_p = \phi\ (T)$. Therefore if we have values for c_p at zero pressure the $\phi\ (T)$ may be determined. To obtain these values the proper correction terms were calculated and subtracted from the values of c_p. The resulting values of $(c_p)_0$ seemed to justify the assumption that $(c_p)_0$ is a linear function of the temperature. This linear relation may not, and probably does not, hold for the entire range of superheat, but it may be assumed as a close approximation, and is the only assumption justified by the experimental data available. The function therefore takes the simple form

$$\phi\ (T) = \alpha + \beta T$$

and the equation for c_p becomes

$$c_p = \alpha + \beta T + \frac{Amn\ (n+1)}{T^{n+1}}\ p \ldots\ldots\ldots\ldots\ldots\ldots [20]$$

67 The constants m and n are those heretofore given in connection with the characteristic equation, and the values finally chosen for α and β are: $\alpha = 0.382$; $\beta = 0.000174$. Replacing $Amn\ (n+1)$ by a single constant C, and substituting the proper value for the various constants the formula for the specific heat becomes:

$$C_p = 0.382 + 0.000174\ T + p\ \frac{C}{T^6} \ldots\ldots\ldots\ldots\ldots\ldots [21]$$

where $\log C = 13.644705$.

68 Values of c_p have been calculated for various pressures up to 400 lb. per sq. in. and for temperatures up to 1100 deg. fahr.; these values are plotted against temperatures in Fig. 7. The experimental determinations are also plotted to show the agreement. The determinations of Regnault, Nernst, Keutel and Voller were made at atmospheric pressure, while those of Wiedemann were at a pressure of about 16 lb. per sq. in. absolute. The agreement between the curve derived from equation [21] for a pressure of 15 lb. per sq. in. and the points representing the determinations of Regnault, Nernst, Keutel and Voller is seen to be very good, while the points representing Wiedemann's determinations lie considerably above the curve.

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69 *Heat Content of Saturated and Superheated Vapor.* Having an explicit formula for the specific heat at constant pressure in terms of the variables p and T, an expression for the heat content in terms of these variables may be easily derived:

$$i = \alpha T + \frac{\beta}{2} T^2 - A\ (n+1)\ p \frac{m}{T^n} - Acp + i_0 \ldots\ldots\ldots [22]$$

For complete derivation of this formula, see Appendix No. 3.

70 The constant of integration i_0 is determined by passing to the saturation limit. Since the constants , β, m, n and c are known,

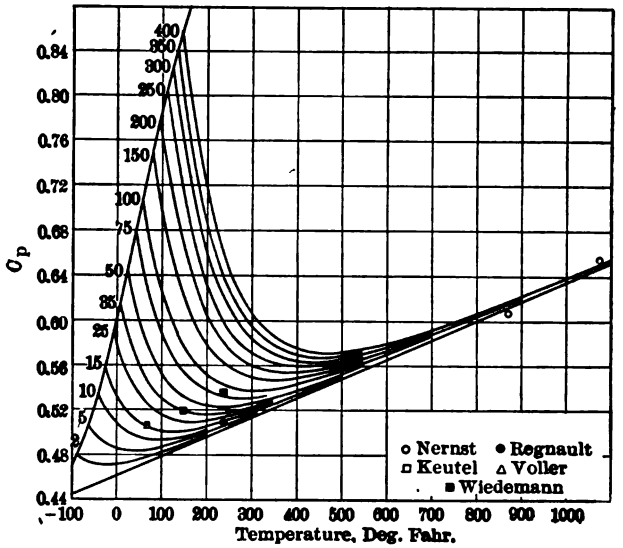

FIG. 7.—CURVES GIVING VALUES OF SPECIFIC HEAT AT CONSTANT PRESSURE

the value of the right-hand member of equation [22], exclusive of i_0 may be found for any given pressure and temperature. If the value of i is known at this point, i_0 may be determined by subtraction. Now for the saturated vapor

$$i'' = i' + r = u + Apv' + r$$

If the energy u be taken equal to zero at 32 deg. fahr., then at this temperature

$$i''_{32} = 0 + Ap_{32}v'_{32} + r_{32}$$

Substituting the proper values as determined by the formulæ for the saturated vapor there results

$$i''_{32} = 0.3 + 546.4 = 546.7$$

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By the substitution of the proper values of p and T in equation [22] there results

$$i = i_0 = 188.7$$

By subtraction $i_0 = 358.0$

Introducing known constants equation [22] becomes, with pressure in lb. per sq. in.

$$i = 0.382T + 0.000087T^2 - p\frac{C}{T^3} - 0.0185p + 358.0 \ldots\ldots\ldots [23]$$

where $\log C = 12.945735$.

71 There are no direct measurements of the total heat or heat content of the superheated or saturated vapor by which equation [23] may be checked. A check on the accuracy of the equation at the saturation limit is afforded by a comparison of the values of the heat content of the liquid, obtained by subtracting values of r calculated by equation [14] from values of i'' calculated by equation [23], with the experimental determinations of Dieterici. This comparison is shown in the following section. A check on the accuracy of the formula in the superheated region may be obtained by a comparison, by means of the law of corresponding states, of the values for the Joule-Thomson coefficient resulting from equation [23] with the values of this coefficient for other vapors. There is also available

TABLE 6. HEAT CONTENT OF LIQUID AS DEDUCED FROM EXPERIMENTS OF DIETERICI AND DREWES.

C'im (t—0° C)	u' Above 0° C. Cal. of 4.222 Joules.	u' Above 0° C. Cal. of 4.184 Joules.	Temperature, Deg. Cent.	Temperature, Deg. Fahr.	u' Above 32° F. in B. t. u.	I' = u' + Apv'	Authority.
1.148	10.65	10.75	9.28	48.70	13.95	19.77	Dieterici.
1.162	10.93	11.03	9.41	48.94	19.85	20.27	
1.141	24.25	24.47	21.25	70.25	44.04	44.67	
1.140	24.57	24.79	21.55	70.79	44.62	45.26	
1.139	38.67	39.02	33.95	93.11	70.23	71.21	
1.147	39.27	39.62	34.24	93.63	71.31	72.30	
1.200	42.03	42.41	35.02	95.03	76.34	77.35	
1.172	48.17	48.60	41.1	105.96	87.46	88.68	Drewes (reliable according to Dieterici.)
1.158	48.35	48.78	41.75	107.15	87.78	89.02	
1.186	61.44	62.00	51.8	125.22	111.60	113.25	
1.163	60.42	60.97	51.95	125.46	109.75	111.41	
1.187	70.74	71.38	59.6	139.3	128.50	130.57	
1.164	72.75	73.41	62.5	144.5	132.15	134.40	
1.179	82.76	83.50	70.2	158.4	150.30	153.07	
1.205	87.48	88.27	72.6	162.7	158.90	161.84	
0.974	11.50	11.60	11.8	53.24	20.89	21.35	Drewes (questioned by Dieterici.)
1.098	21.62	21.81	19.7	67.46	39.26	39.86	
1.069	22.82	23.02	21.35	70.43	41.44	42.08	
1.140	34.61	34.92	30.36	86.64	62.85	63.72	
1.148	35.83	36.16	31.21	88.17	65.08	65.97	
0.7065	—10.49	—10.59	—14.85	5.27	—19.06	—18.91	

a set of throttling experiments performed by Wobsa. This check is given in Appendix No. 4 and Fig. 10.

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72 *Heat Content of the Liquid.* The values of heat content of the liquid may be found by subtracting the values of r found by equation [14] from the values of i'' found by equation [23]. The most important check on these values is derived from a series of experiments performed by Dieterici and by Drewes working in Dieterici's laboratory. In these experiments the quantity measured was the amount of heat given up by a certain weight of a mixture of

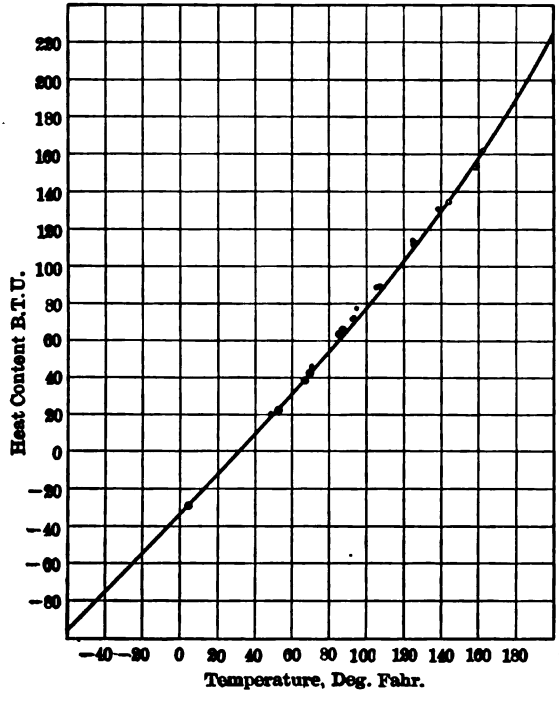

FIG. 8.—COMPARISON OF CALCULATED VALUES OF HEAT CONTENT OF LIQUID WITH VALUES DEDUCED FROM EXPERIMENTAL WORK OF DIETERICI AND DREWES

saturated and liquid ammonia cooling at constant volume in a sealed tube. This quantity was corrected for the heat due to the latent heat of the portion of vapor condensed and the remaining amount of heat was divided by the change in temperature to obtain the mean "inner" specific heat of the liquid over that temperature range. In his paper Dieterici gives only the formula which he chose as best representing the results of his experiments, which states that the mean "inner" specific heat between t and 32 deg. fahr. $= 1.118 + 0.000578\ (t - 32)$.

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Since this is a linear function of the temperature it follows that the instantaneous "inner" specific heat $= 1.118 + 0.001176\ (t - 32)$. The original data of the experiments are not given, but Professor Dieterici has kindly furnished the values which he actually obtained for the mean "inner" specific heat and also a copy of Mr. Drewes' dissertation containing the values obtained by him. If each of these values of the mean "inner" specific heat is multiplied by the temperature range covered the result will be approximately equal to the internal energy u above 32 deg. fahr. at the temperature t. Since $i' = u' + Apv'$, in order to obtain values of i' the product Apv' corresponding to the temperature t must be added to the value of u' obtained as described. The results of these calculations appear in Table 6. Since Dieterici reported his results in terms of a mean calorie equal to 4.222 joules, while in the present investigation a mean calorie of 4.184 joules is used, all of Dieterici's heat quantities must be multiplied by 1.009. The table includes the determinations made by Dieterici himself and all of the determinations made by Drewes; part of the latter are called reliable by Dieterici, while the rest are marked "falsch" in

TABLE 7. SUMMARY OF DETERMINATIONS OF THE SPECIFIC HEAT OF LIQUID AMMONIA.

Temperature, Deg. Cent.	Temperature, Deg. Fahr.	Specific Heat of Liquid.	Authority.
62-30	144-86	1.22876	von Strombeck.
20-0	68-32	1.02	Elleau and Ennis.
77.7	139.9	0.886	Ludeking and Starr.
20-16	68-61	1.094	A. J. Wood.

the copy of Drewes' dissertation loaned by Dieterici. The ground for this statement is not given. In Fig. 8 Dieterici's values are plotted as black dots, and those of Drewes as circles. The values questioned by Dieterici are indicated by double circles. The curve represents the values found by the use of equations [14] and [23]. It is seen that in several cases the curve passes between the Dieterici points and the doubtful Drewes points.

73 Since the quotient obtained by dividing the change in i' between two temperatures by the difference in temperature is very nearly equal to the specific heat, the other determinations which have been made of the specific heat may be used to check the calculated values of i'. Table 7 contains a summary of the dterminations of the specific heat of the liquid in addition to the work of Dieterici and Drewes already given; this includes the work of Elleau

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and Ennis, von Strombeck, Ludeking and Starr and A. J. Wood. In Fig. 9 these values are plotted, together with the curves representing the following equations used in the computation of various tables:

Dieterici.....$c' = 1.118 + 0.001156\ (t - 32)$
Zeuner.....$c' = 1.01235 + 0.00468\ (t - 32)$
Wood.....$c' = 1.12136 + 0.000438t$
Ledoux.....$c' = 1.0058 + 0.0020322\ (t - 32)$
Elleau and Ennis.....$c' = 0.9834 + 0.0020322\ (t - 32)$
Peabody.....$c' = 1.1$ constant

74 The full line curve represents the values of the tangents to the heat content curve of the present investigation. Since according

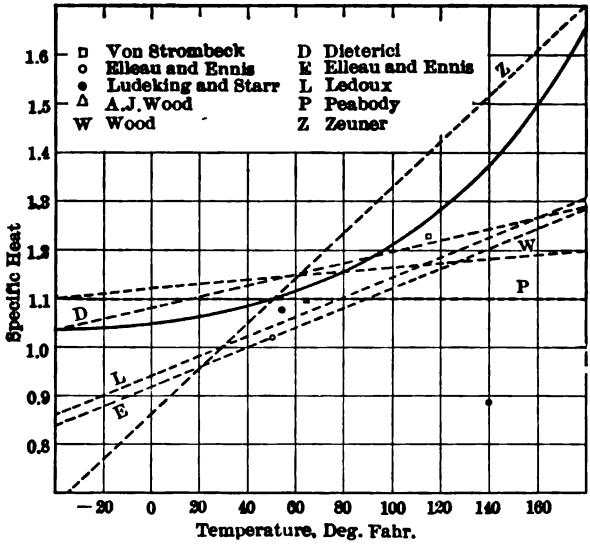

FIG. 9.—COMPARISON OF VARIOUS DETERMINATIONS OF SPECIFIC HEAT OF LIQUID AND VARIOUS EQUATIONS PROPOSED TO REPRESENT SAME QUANTITY

to modern ideas of the critical point the specific heat of the liquid there becomes equal to plus infinity, the full line curve is of a more rational form than any linear relation.

75 *Entropy of the Saturated and Superheated Vapor.* An expression for the entropy is readily derived from the characteristic equation and the expression for c_p:

$$s = a \log_e T + \beta T - AB \log_e p - Anp \frac{m}{T^{n+1}} + s_0 \ldots\ldots [24]$$

For the complete derivation of this equation, see Appendix No. 3.

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76 The constant s_0 is determined by passing to the saturation limit at 32 deg. fahr., where $s' = 0$ and therefore $s'' = \frac{r}{T}$. Substituting this value for s in the left-hand member of equation (s) and the proper values of p and T in the right-hand member, s_0 is found to be equal to —0.82656. Substituting this value and the known values of the other constants, and passing to common logarithms equation [24] becomes

$$s = 0.8796 \log T + 0.000174\, T - 0.2695 \log p - \frac{p}{T^2} C - 0.82656 \ldots [25]$$

where $\log C = 12.866554$.

ACKNOWLEDGMENT

77 Acknowledgment is hereby made to Prof. G. A. Goodenough of the University of Illinois, who suggested this investigation and who has given to it his hearty encouragement and his personal supervision.

78 The investigation was made under the auspices of the mechanical engineering department of the Engineering Experiment Station of the University of Illinois, and complete tables based upon the formulæ set forth in this paper, together with a Mollier diagram and a full bibliography of the subject, will in due time be published as a bulletin of the station.

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APPENDIX No. 1

METHOD OF CONSTRUCTION OF FIG. 1

79 Using formula [7] to obtain the saturation temperatures of ammonia from those of water

$$\frac{1}{T_a} = c\,\frac{1}{T_w} + k$$

Let

$$\frac{1}{T_w} = y \text{ and } \frac{-1}{T_a} = x$$

then

$$-x = -cy + k$$

Since y is a function of the water vapor temperature corresponding to pressure p, y is also a function of p; the value of y for a given value of p may be found by making use of the tables of water vapor pressure; x is a function of the temperature of the ammonia corresponding to this same vapor pressure p; the curve giving x as a function of y is evidently a straight line.

80 Since y is a function of the pressure p and x a function of the corresponding temperature, the values of x and y may represent their respective values of pressure and temperature. The corresponding values of saturation temperature and vapor pressure may be read directly from the diagram.

81 Fig. 1 was constructed in the following manner: Integral values of temperature were assumed and the corresponding values of x were computed according to the relation $x = -\frac{1}{T}$. These x's were then laid off to a convenient scale and each labeled with the temperature to which the value of x corresponds. Integral values of pressure were assumed, the corresponding values of temperatures found from steam tables, and the corresponding values of y computed according to the relation $y = \frac{1}{T}$. These y's were then laid off to a convenient scale and each labeled with the pressure to which the value of y corresponds.

82 The value of vapor pressure at a given temperature as taken from the Marks and Davis steam tables was found to agree with the value given by the new Marks formula with sufficient accu-

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racy up to a temperature of 400 deg. fahr.; above this temperature the values differed materially. In the construction of the chart, therefore, the steam tables were used to find the pressures corresponding to temperatures below 400 deg. fahr. and the newer formula was used to find the pressures corresponding to temperatures above that point.

83 Table 8 shows the calculations for a few of the values of Fig. 1.

84 In order to settle upon the most probable location of the straight line representing the pressure-temperature relation of saturated ammonia upon this chart the experimental data must be

TABLE 8. SAMPLE CALCULATIONS OF THE CO-ORDINATES OF FIG. 1.

ABSCISSAE.

Temperature, Deg. Fahr.	Absolute Temperature.	Reciprocal of Absolute Temperature.	Corresponding Value of x, In., referred to the point — 10 as Origin = — (8000 × ± — 10).
—100	359.64	0.0027806	12.244
—50	409.64	0.0024412	9.529
0	459.64	0.0021756	7.405
+50	509.64	0.0019622	5.697
100	559.64	0.0017869	4.295
150	609.64	1.0016403	3.122
200	659.64	0.0015160	2.128
250	709.64	0.0014092	1.273

ORDINATES.

Pressure, Lb. per Sq. In.	Corresponding Saturation Temperature of Water Vapor, Deg. Fahr.	Absolute Temperature.	Reciprocal of Absolute Temperature.	Corresponding Value of y, In., referred to the point — 18 as Origin = — (20000 × ± — 18)
1	101.83	561.47	0.0017810	17.621
5	162.28	621.92	0.0016079	14.158
10	193.22	652.86	0.0015317	12.634
50	281.0	740.64	0.0013502	9.004
100	327.8	787.44	0.0012699	7.399
500	467.2	926.84	0.0010789	3.579
1000	544.9	1004.54	0.0009955	1.910
1700	613.4	1073.04	0.0009319	0.639

TABLE 9. SUMMARY OF DETERMINATIONS OF CRITICAL DATA FOR AMMONIA

Investigator.	Date.	Temperature, Deg. Cent.	Pressure, Atmospheres.	Temperature, Deg. Fahr.	Pressure, Lb. per Sq. In.
Dewar	1884	130.0	115.	266.0	1690.0
Vincent and Chappuis	1886	131.0	113.	267.8	1660.8
Jaquerod	1908	132.3	109.6	270.1	1610.7
Scheffer	1910	132.1	111.3	269.8	1635.7

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plotted. The pressures observed by Pictet over a temperature range of —22 to 122 deg. fahr. agree almost exactly with those observed by Regnault; they are neither tabulated nor plotted. Faraday's results are quite inconsistent with those of Regnault, and are neither plotted in Fig. 1 nor given weight in the determination of the constants in the equation.

85 The two points in the upper right-hand corner of Fig. 1 represent the experiments at the critical point. The open square shows the values given by Vincent and Chappuis and the solid triangle the values given by Dewar. The values from which these points were plotted are given in Table 9.

86 This table also contains the values for critical data given by Jaquerod and Scheffer, which were found after the plate for Fig. 1 was made.

APPENDIX No. 2

DERIVATION OF EQUATION [19]

$$c_p = \phi\, T + \frac{Amn\,(n+1)}{T^{n+1}}\, p$$

87 The Clausius relation is expressed by the equation

$$\left[\frac{\delta c_p}{\delta p}\right]_T = -\,AT\left[\frac{\delta^2 v}{\delta T^2}\right]_p$$

The derivative in the right-hand member is determined from the characteristic equation. Thus from equation [18]

$$\frac{\delta v}{\delta T} = \frac{B}{p} + \frac{mn}{T^{n+1}} \qquad [26]$$

and

$$\frac{\delta^2 v}{\delta T^2} = -\,\frac{mn\,(n+1)}{T^{n+2}} \qquad [27]$$

Substituting the second derivative in the Clausius relation the result is

$$\left[\frac{\delta c_p}{\delta p}\right]_T = \frac{Amn\,(n+1)}{T^{n+1}} \qquad [28]$$

Taking T as a constant and integrating with respect to p as the independent variable, the result is

$$c_p = \frac{Amn\,(n+1)}{T^{n+1}}\, p + \text{constant of integration.}$$

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The constant of integration may be a function of T, since T was held constant during the integration; hence

$$c_p = \phi\ (T) + \frac{Amn\ (n+1)}{T^{n+1}}\ p \ldots\ldots\ldots\ldots\ldots [29]$$

APPENDIX No. 3

DERIVATION OF EQUATIONS [22] AND [24]

$$i = a\ T + \frac{\beta T^2}{2} - A\ (n+1)\ p\ \frac{m}{T^n}\ Ac_p + i_0$$

$$s = a \log_e T + \beta T - AB \log_e p - Anp \cdot \frac{m}{T^{n+1}} + s_0$$

88 Having an explicit formula for the specific heat at constant pressure in terms of the variables p and T, an expression for the heat content in terms of these variables may be easily derived. For this purpose the general equation

$$dq = c_p dT - AT \left[\frac{\delta v}{\delta T} \right]_p dp \ldots\ldots\ldots\ldots\ldots\ldots [30]$$

is most convenient. Since the heat content is defined by the relation

$$i = A\ (u + pv)$$

then

$$di = A\ [du + d\ (pv)]$$

or

$$di = dq + Avdp$$

Hence by substitution in equation [30] there results

$$di = c_p dT - A \left[T \frac{\delta v}{\delta T} - v \right] dp \ldots\ldots\ldots\ldots\ldots [31]$$

From the characteristic equation

$$\frac{\delta v}{\delta T} = \frac{B}{p} + \frac{nm}{T^{n+1}}$$

whence

$$T \frac{\delta v}{\delta T} - v = (n+1)\ \frac{m}{T^n}$$

Substituting this and the general expression for c_p in equation [31] the result is

$$di = (a + \beta T)\ dT + Amn\ (n+1)\ p\ \frac{dT}{T^{n+1}} - \frac{Am\ (n+1)}{T^n}\ dp - Acdp$$

[32]

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Since i depends upon the state of the substance only, the second member of equation [30] must be an exact differential. The integral is readily found to be

$$i = a\,T + \frac{\beta}{2}\,T^2 - A\,(n+1)\,\frac{pm}{T^n} - Acp + i_0 \ldots\ldots\ldots [33]$$

89 An expression for entropy is readily found from equation [30]. Thus

$$ds = \frac{dq}{T} = c_p\,\frac{dT}{T} - A\left[\frac{\delta v}{\delta T}\right]_p dp \ldots\ldots\ldots\ldots\ldots [34]$$

Introducing in equation [34] the expressions previously derived for c_p and $\left[\frac{\delta v}{\delta T}\right]_p$,

the result is

$$ds = \left[\frac{a}{T} + \beta\right]dT + Amn\,(n+1)\,p\,\frac{dT}{T^{n+2}} - \frac{ABdp}{p} - \frac{Amn}{T^{n+1}}\,dp \qquad [35]$$

The integral of equation [35] is

$$s = a\,\log_e T + \beta T - AB\,\log_e p - Anp\,\frac{m}{T^{n+1}} + s_0 \ldots\ldots\ldots [36]$$

APPENDIX No. 4

TEST OF VALIDITY OF EQUATION [23] BY MEANS OF THE LAW OF CORRESPONDING STATES.

90 Since i is constant in a throttling process, the Joule-Thomson coefficient μ may be defined as the derivative

$$\left[\frac{\delta T}{\delta p}\right]_i$$

From calculus

$$\left[\frac{\delta T}{\delta p}\right]_i = -\frac{\dfrac{\delta i}{\delta p}}{\dfrac{\delta i}{\delta T}}$$

and from the definition of heat content i

$$\frac{\delta i}{\delta T} = c_p$$

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Hence

$$\mu = \left[\frac{\delta T}{\delta p}\right] = -\frac{1}{c_p} \cdot \frac{\delta i}{\delta p}$$

or

$$\mu = \frac{A}{c_p}\left[\frac{m(n+1)}{T^n} + c\right] \ldots\ldots\ldots\ldots\ldots\ldots [37]$$

91 From equation [37] it is seen that μ varies with the pressure; as the temperature rises, however, the influence of pressure decreases. Joule and Kelvin, working with gases far removed from the saturation limit, found that μ varies inversely as the square of the absolute temperature. The experimental values of μ for steam expressed in pounds per square inch and degrees fahrenheit were reduced by multiplying by 2.56, a factor which is the ratio of the critical pressure of water (2947 lb. per sq. in.) to the critical temperature (1149 deg. fahr.), these critical values being the ones determined by Cailletet and Colardeau. Davis gives a curve which he says represents the experimental values for water in the best possible manner; the values in this curve are those translated back to ordinary units. Later determination of the critical constants for water by Holborn and Bauman give 3200 lb. per sq. in. for the critical pressure and 1166 deg. fahr. for the critical temperature, Table 10. If then the values of μ on the Davis curve are multiplied by $\frac{3200}{1166}$, or 2.745, and the temperatures are divided by 1166, there results a curve expressing the variation of μ with temperature, both expressed in reduced units, according to the best available experimental data.

TABLE 10. SUMMARY OF DETERMINATIONS OF CRITICAL DATA FOR WATER.

Investigator.	Date.	Critical Temperature, Deg. Fahr.	Critical Pressure, Lb. per Sq. In.
Nadeidine	1885	676.6	....
Battelli	1890	687.7	2859
Cailletet and Colardeau	1891	689.0	2994
Strauss	1892	698.0	2873
Traube and Teichner	1904	705.2	....
Holborn and Bauman	1910	706.3	3200

92 This curve is shown in Fig. 10 as the heavy full line curve. The values resulting from [37] and those resulting from Wobsa's equation for ammonia may now be compared with the values for water. Wobsa's throttling experiments were performed at pressures

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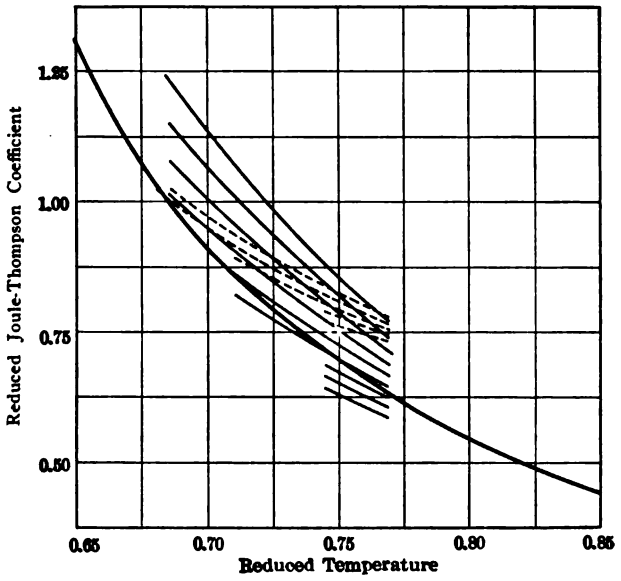

FIG 10.—COMPARISON OF VALUES OF REDUCED JOULE-THOMSON COEFFICIENT FOR AMMONIA ACCORDING TO WOBSA AND VALUES RESULTING FROM EQUATION (37), WITH VALUES FOR WATER AS GIVEN BY DAVIS

of from 2 to 10 atmospheres and at temperatures of 42.8, 60.8, 86 and 104 deg. fahr. The values of μ at the same pressures and temperatures have been calculated from [37] and are shown in Fig. 10 as full line curves, while the values resulting from Wobsa's equation are shown as dotted curves. It is seen that while the full line curves form a rather strongly divergent brush, yet the Davis line passes through the center of the brush and it appears that the brush would converge into the Davis curve at high temperatures. On the other hand the brush of dotted curves has an entirely different trend and would not merge into the Davis curve.

DISCUSSION.

R. C. Carpenter.—I wish to express my appreciation of both Mr. Marks' and Mr. Mosher's papers presented on this subject. I think these papers represent the best and most reliable work that has been done in the world, and I am very glad indeed that this Society has been instrumental in getting these two papers together and getting this information in shape where it can be used.

Lionel S. Marks.—Mr. Mosher is fully saturated with ammo-

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nia; to my knowledge he has been working on nothing else for the last twelve months. What he has done is a very different thing from what I have done. I have merely discussed what other people have done; Mr. Mosher has added to our knowledge by devising a new characteristic equation, which is undoubtedly of the same order of accuracy as the Wobsa equation, though it may not be quite so good. Although I have known of his work I have not had the opportunity until this moment of seeing his paper, so I am not able to discuss it. I observe that he has not used all the experimental data available, but I have no doubt that when he does so he will find very good agreement. I would also like to predict, without having seen his data at all, that the tables derived from the two sets of equations, the Wobsa and Mosher equations, will be found to differ very little.

V. R. H. Greene.—Some two or three years ago I had occasion to plot an entropy diagram based on each of the four existing ammonia tables, Ledoux, Zeuner, Peabody and Wood, between the limits of 95 degrees Fahr. and zero, and I found the lines curve similar down to 30 degrees. Beyond that point they both became ragged and unreliable. In this particular paper presented by Professor Marks, that variation seems to have disappeared and the lines curve down to zero in apparently true curves, showing that in all probability that table presents nearer the actual condition than any we have had before. At the same time, it has also helped greatly in checking out some experimental data that I have examined. I have even taken the time to hunt up some of the existing tests on record in so far as the weighing of liquid ammonia is concerned, and I find that you can get a much nearer heat balance with these new properties of ammonia than with any of the four tables in existence previous to this.

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No. 109

Discussion of the Topic—THE USE OF ICE IN REFRIGERATOR CARS IN WINTER TO PREVENT FREEZING OF PERISHABLE PRODUCTS IN TRANSIT.

Peter Neff.—I haven't very much to say about it, but to set the ball rolling I will say that the question came up to me last year in this way: It was said there were two cars of eggs shipped in the winter time and one had the ice bunkers full of ice and came through all right; the other had nothing in the bunkers and the eggs froze. The party making the inquiry asked if it wasn't a logical conclusion that the use of ice in winter was a good thing. I believe that if we think of this matter a little more carefully we will see where the trouble lies. As I understand, refrigerator cars are built to avoid the loss of the cold air out of the bottoms; they don't seem to pay quite so much attention to the tops. If any of you have stood on an icing platform and seen them close up the openings on top I think you will appreciate that point. It seems to me that what happened was simply this, that the ice bunker that was full of ice prevented the egress of the warm air when the cold air tried to get into the bottom or through these leaks on top, whereas the car that had nothing in the ice bunkers offered a chance for the warm air to pass out through the openings in the top of the car, and every cubic foot of that warm air that went out was replaced by a cubic foot of cold air that came in, and it didn't take very long to put that car below the freezing point and destroy the products. Had that car been closed up tight, or had they filled the ice bunkers full of hay, the car would have come through all right, because the hay would have prevented the warm air from getting out through the bunkers.

Eugene W. Lewis.—I went through an experience of that kind in 1894. We had a number of cars to load in Chicago, and, if I remember right, the temperature was around ten or twelve above zero. I went to the Merchants' Dispatch and suggested putting ice in the bunkers. I thought they were going to call a policeman; they thought I was crazy. What prompted me to make the suggestion was the ice acting as an insulator on our expansion coils. However,

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we tried it, and the goods went through all right. We did use some straw, but not in the bunkers.

Louis Block.—Where did you use the straw?

Eugene W. Lewis.—In the bottom of the car, not on top. That happened 18 years ago.

Charles H. Herter.—I think I can reason that out. The temperature of the ice was 32 and the air outside zero, or 10 degrees above. The air coming into the car could not reduce the temperature in the car without also reducing the temperature of the ice. The presence of the ice tended to prevent or, at any rate, delayed the lowering of the temperature of the car. The ice acted as a heater for the time being.

President Shipley.—Suppose the air can't get in. Why should the cold weather make a special effort to cool the ice and not freeze up the eggs?

Charles H. Herter.—All the better. But the "cold" still penetrates the walls, cooling the air inside, causing it to circulate and thus to distribute the "cold" not only over the goods, but also over the relatively warm ice.

President Shipley.—I believe, like Mr. Neff, that the difficulty in this case is because the bunkers are made to receive ice and very little pains are taken to make them tight; they throw the ice in the bunkers and the ice acts as a sort of a seal and stops the circulation of air. I believe that if the bunkers were filled with old hats or old coats or straw or hay the result would be better than filling them with ice. Of course, there is something in what has just been said about the volume of material to be cooled. If the air affecting the goods carried had to pass over the ice before it entered the car, naturally it would have to cool the ice before it would get in contact with the goods, but if the bunkers are sealed the cold comes in from the sides, ends, bottom and top of the car, hence is not affected materially by what may be in the bunkers. I believe if we filled that up with dirt or any substance, or sealed it up well, we wouldn't have so much trouble. There has been some talk about putting cans of water in the bunkers and letting them freeze up, thereby taking up some of the cold entering the car. I don't know whether that would do any good or not. What do you think about it, Mr. Block?

Louis Block.—I agree with you and Mr. Neff. I think if you'd insulate that car well and paste up all the openings you won't get sufficient cold air in to freeze the eggs. If you could put in water in cans it would be a very good thing; that is what he farmer does

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when he don't want his pumpkins to freeze in the cellar. He puts water in the cellar.

Peter Neff.—I just wanted to add one word; possibly I did not bring it out clearly enough. As the cars are now constructed, the warm air has a pretty good chance to get out of the car, whereas, in the summer time, when the air outside is warm and the car is cold, the attempt to get out is through the bottom.

Louis Block.—Then you think the tops of refrigerator cars are not perfectly insulated?

Peter Neff.—Not perfectly.

Conrad H. Young.—I might state that I have had a lot of experience in talking with the builders of refrigerating cars with regard to insulation. They don't insulate them very well, and they claim that it is not worth while to insulate a refrigerator car in comparison with fixed buildings, because of the short life of the car. I think, as Mr. Neff states, that this is a case of displacement of air by actual loss through circulation rather than heat loss.

F. W. Pilsbry.—When they fill the bunkers they put in some big chunks of ice and then take a split-bar and jam the ice down and fill it up to where the trap door goes on, and that stops the circulation of air, it stops the cold getting in or the heat getting out through that place. They crowd that ice in there so tight that there can't be any circulation from the outside, and that is probably what occurred in those two cars.

Theodore Kolischer.—I will take the liberty of transgressing for two minutes. I have a funny story apropos of this icing cars in summer to keep them cold and icing cars in winter to keep them hot. It reminds me that when I was in Russia some years ago I was told that the Russian peasants wore their fur coats all the year round. These coats are made of sheepskin tanned with the wool on. In winter they turn the coat inside out to keep the cold out. In the summer time they reverse it to keep the heat out. That reminds me very much of icing cars both summer and winter to produce opposite results.

F. E. Matthews.—We don't have to go to Russia for engineering of that kind. We have right here in New York an architect who proposed to put cork on the inside of coolers to keep the cold in and asbestos on the outside to keep the heat out.

Morgan B. Smith.—Another example is the Esquimo in the North, who lives in an ice hut with the temperature far below zero on the outside, and keeps it warm.

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G. H. Crawford, Jr.—It seems highly improbable that ice in the bunkers of a refrigerator car prevents the freezing of the produce in the car during cold weather. The ice capacity of the ordinary refrigerator car is 10,000 pounds. The produce in such a car weighs (for fruit) from 15,000 to 25,000 pounds. The total heat capacity of the ice (B.t.u. times degrees change of temperature) is about one-quarter the total heat capacity of the produce. If the ice should give up enough heat to the produce to prevent the latter from cooling through one degree, the ice itself would have to drop through four degrees. This process of heat interchange could not go on at all if the produce was above 32 degrees; otherwise, heat would be flowing from a cooler to a warmer body, or from the produce to the ice. In fact, ice in the bunkers would help the freezing of the load, should the outside temperature be low. It would absorb heat from the produce until both were at the same temperature. After that point had been reached, a low outside temperature would tend to cool both ice and produce, and eventually freeze the latter. Ice would accelerate the cooling down to 32 degrees, and then act as a very slight retarder of a further temperature drop.

Charles H. Herter.—As far as I am able to find out, the temperature depression ordinarily obtained with the ice alone is between 50 and 45 degrees and very seldom 42, consequently you have at least the difference between 42 and 32 degrees to draw on for heating effect.

President Shipley.—This is a winter proposition that we are talking about.

F. E. Matthews.—I would like to ask, as a matter of fact, has water ever been used for the purpose set forth?

President Shipley.—I have understood it has been used. The trouble is that it destroys the can by freezing the ice from the top as well as the sides and bottom, thus bulging or bursting the cans. It may be possible to make a can which will stand this strain, but you must take into consideration the swashing of the water in the cans when the train is in motion.

Fred W. Wolf.—As a matter of fact, eggs taken from a refrigerator immediately begin to sweat. Moisture promotes freezing of a product because it makes it a better thermal conductor. Having ice in the car at one end induces a circulation and this circulation has a tendency to dry off the eggs. A dry egg might last longer in a low temperature before it froze than a moist egg.

N. H. Hiller.—Is the question whether ice in the bunkers pre-

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vents freezing, or is it that the ice acts as a balance wheel? Cars have to pass through warm days and cold nights; is it that the ice would keep a more uniform temperature in the car than if the car were empty?

F. W. Pilsbry.—It seems to me that the minute you put ice in the car you take the heat out of the produce in the car, lower the temperature of the produce as low as you can do it with that ice. Putting ice in the car in the winter time, you are surely doing your goods more harm than benefit; there isn't any question about that.

W. H. Dohrmann.—In zero weather, isn't it a fact that the ice itself is warmer than the atmosphere? You can carry a piece of ice in the winter time in your hand and it will actually feel warm to you.

President Shipley.—Isn't it a fact that the reason that ice feels warm to a man in winter is because his hand is dry and there is little air in between his flesh and the ice?

Eugene W. Lewis.—I might say in regard to that that it would be like a man some years ago in Jersey City, who came into our plant on a very cold day and went up into his apple room and says: "My apples are going to spoil; you have got the temperature too high." I said: "Your blood is a pretty poor thermometer. Look at the thermometer. " He looked at it, but thought it might have been fixed. He came along there again on a warmer day in April or May, and the same room, at the same temperature, was too cold.

Henry Vogt.—I believe that the humidity of the car determines whether the ice will lower the temperature of the car or not. I have seen the temperature in rooms 10 degrees below zero and the ice in those rooms disappear. What I mean by that is that it actually thawed. In fish storage rooms the ice thaws away from the fish itself, and blocks of ice are placed in the rooms in order to supply moisture for the room. Now I was just thinking, in districts where the variation in humidity is considerable, ice in the car would be a help rather than a detriment.

Peter Neff.—Speaking about this matter of ice melting, or, at least disappearing, of course you have seen a thin sheet of ice on a sidewalk on a cold day gradually disappear; it is because of evaporation. Evaporation takes place on an ice surface all the time, but it is a very slow process. Now, about Mr. Dohrmann's taking ice in his hand and carrying it around in the winter time and it felt warm, I suppose he got that up the Hudson, where it had been in the house all summer and got warmed up to about 32 degrees, and the air was about 15 below zero, and probably it did feel nice and warm.

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President Shipley.—There is this much to be said about the Esquimo and his hut. When you stop to consider the matter, the Esquimo's house—they have a fierce name for it; I can't pronounce it—is made of ice. The Esquimo is on the inside and creates heat, and the cold weather from the outside has got to come through this ice of which the house is made to get to him, and the ice, acting as an insulator, prevents that cold from the outside, to a great extent, from gettting in, so he only has to contend with the internal temperature and not the external temperature. I have talked with men who have been around Alaska, and they tell me about the little oil stoves that they use; they dig a hole in the snow and cover over the top and get down there with their little oil stove and keep warm: they say that the stove heats up the space they are in and that the snow and ice about them act as an insulator. You can't compare that with the proposition we have before us, that is, of filling bunkers in a car at each end and expecting that to insulate the whole car. There is no question about putting ice in a car, that it will reduce the temperature of that car to somewhere near the temperature of the ice. Now, if you have done that, then any additional cold is going to do you more harm than if you hadn't put the ice in the bunkers, that is, if it's the cold you're afraid of. Mr. Hiller points out the possibility of damage being done by fluctuation in temperature, going up on a mountain where it is cold and then coming down in a valley where it is warm, as the cars have to do in coming across the Continent. If that is where the trouble comes in, then the ice in the car would be an advantage in tending to keep a more uniform temperature. There are a good many questions involved in this subject, and I believe it's a good deal as some of us understand it, that is, the car builders and owners don't pay enough attention to the insulating of the cars.

F. E. Matthews.—I want to clinch one point that was almost made; that is, that the evaporation of the ice may have some effect on temperatures. By the evaporation of ice you would get a considerable heat absorption or refrigerating effect, probably equal to the sum of the latent heats of fusion and vaporization. A close analogy is the rotting of wood. Take a fence post for example. The slow rotting of that post in the ground is supposed to give off the same amount of heat that would be given off by the burning of the same number of pounds of wood by actual combustion, notwithstanding the fact that the action, like that of vaporization of ice, through sublimation, proceeds very slowly. The effect of sublima-

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tion of ice, increasing with lower atmospheric humidities, would be to promote rather than prevent freezing.

John E. Starr.—I think that the answer to this whole question is good refrigerator cars. I don't know of any department in the line of refrigeration or insulation, or anything pertaining to refrigeration, that has been so badly developed as the refrigerator cars. The builders of refrigerator cars, as a rule, look at price only, and as far as my observation has gone, and I have had some opportunity in the last year or two to get some insight into the refrigerator car building business, the building of refrigerating cars, so far as the question of insulation is concerned, has been carried on by rule of thumb, haphazard management and guesswork. These various questions about ice keeping the car warm have come up without any regard to the conditions in the particular case. I don't believe that there is a single instance where they can show the history of a car where they have made the claim that the ice has helped the car out through the cold weather.

As a rule, refrigerator cars in cold weather originate in a warm climate. They are generally started and iced either in the West or the South. They proceed to their destination from a warmer to a colder climate, and there is refrigeration needed in the first part of the trip, and in the latter part of the trip, perhaps for a day or two or three days, the car is surrounded by temperature much lower than the temperature desired in the car itself. Sporadic cases have come up, I don't believe that they are general, and I don't even believe that they can be true, where it has seemed to the operators of refrigerator cars that the ice helped them out. I do not think that any of those cases where such claim has been made are sufficiently authenticated to warrant any consideration whatever.

A fairly well built car, whether there is ice in it or not, will stand a couple of days of cold weather without material injury to the fruit or to whatever perishable product is placed in the car. The great problem with refrigerator cars, it seems to me, is to evolve a car which, being loaded and starting in a warm climate, as most of them are, will carry to destination through an increasingly cold temperature and arrive without freezing the goods. I don't believe that the ice in the car has anything to do with keeping up the temperature after it has reached the colder climate; on the contrary, if anything, it would assist in lowering the temperature of the car, and I believe most firmly that many of these statements which have been made about ice keeping the car warm in cold weather are not

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properly based. I do believe that a refrigerator car, under ordinary conditions of transit, can be iced in a warm climate, say in California, where for a day or two, they will need the icing, and, with the ice still in the car, it can stand the other two or three days of cold temperature without injury to the goods, always provided that the car is well built, but it is only within the last few years that they have built a refrigerator car worthy of the name.

There are none of the refrigerator car builders, as far as I know, who have ever made a test on a refrigerator car under operating conditions. They have made certain tests on cars placed in the yard and have simply noted the temperature inside of the car, the general temperature outside of the car and the amount of ice melted, in a very rough sort of a way. I have had a great many talks with the American Car and Foundry Company people, and, so far as I know, they have never reduced their results to the rate of transmission per square foot per degree of difference. They have placed a car in the yard, never noted the conditions of sunshine, never noted why a car at one end of the yard and a car at the other end of the yard may be built exactly the same and give different results; in fact, I have noted from tests that they have shown me that they have given different results with the same kind of car, because they were under different exposures. They have never, so far as I know, accurately tested a car under working conditions. A car in motion is an entirely different thing from a car standing still. We all know that the transmission of heat through a given surface is in a certain ratio to the speed of the fluid passing over that surface. Take, for example, a car traveling at 40 miles an hour, as some of them do, or an average of at least 25, and some of the car lines, for example, the line from Florida, come up on a schedule of 30 miles an hour, which means that at times they are traveling from 40 to 50; such a car will transmit much more heat from the outside to the inside than a car standing still on the track in still air. I think that Mr. Young will substantiate that statement on general principles. I think that anybody who is familiar with the transfer of heat will agree with me. I cannot conceive and do not believe that the use of ice in the car in cold weather will tend to keep up the temperature of the car. There is certainly no scientific reason for it, and I don't believe that there is any well substantiated evidence of it.

President Shipley.—There was quite a discussion as to whether filling the bunkers with hay or filling the bunkers with ice would

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have the most beneficial effect. You should give us your expert opinion on that point.

John E. Starr.—Do I understand that this means the protection of the car in cold weather—below 32?

President Shipley.—Yes.

John E. Starr.—I should think the hay would be the best.

Conrad H. Young.—Mr. Starr said that he didn't believe any experiment had ever been made. I want to say that in my early connection with insulation products, back in 1899 and 1900 and 1901 and 1902, we made a very aggressive raid on the car builders. I visited car builders all over the United States, and they would not consider anything at all in the way of efficient insulation that cost money. There were two reasons; one reason is that they don't want to get a bulky car and they can't get more than a certain minimum size for the outside dimensions of the car; and when you get to that they want to get all the space they can inside, so they won't figure on insulation that is thick enough in proportion to what we use in insulating buildings. Back in 1901 or 1902 Nonpareil cork board insulation was furnished the American Car & Foundry Company of St. Louis to double the thickness of the insulation. Those cars were built for a line down in Mexico. Our old friends, Morris & Butt, of Kansas City, whom some of you older gentlemen were acquainted with, were interested in those cars. I saw Mr. Morris in Kansas City before he died and he told me that the saving was very great. I asked him if they had made any records, which they promised to do in consideration of the fact that they got some of this material for nothing. He said he didn't think they had. Since that I have never heard whether any actual data was developed from those cars or not. I think they are on the line, if still in existence, that runs into Chihuahua. That is the only case that I know of in my experience of twelve years or more where any attempt was made to get data in connection with refrigerating cars. The builders of refrigerating cars are not interested at all in refrigeration or insulation or heat loss or anything else; it is the people they build the cars for, and when you get back to them, they don't care much about it, either.

J. H. Bracken.—I am disappointed that this discussion should come up to-night, because I had paid a little attention to it in Chicago and expected to have something to offer which would be worth while. I expect to get a letter to-day or to-morrow from some railroad man to whom I have written, but at any rate I can testify, in the first place, to the prevalence of the belief among railroad men that ice in

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refrigerator cars in winter prevents freezing. It is almost a universal belief. When I got this program of the society I talked to three men, the operators of three of the largest refrigerator lines out of Chicago, and they all did not *believe* that ice would save the products from freezing; they *knew*, they absolutely knew that ice would save them. If you analyze the proposition, it appears to be a most childish myth.

The refrigerator car is a box; granting that it has some insulation in it, it is an insulated box; assuming the outside temperature to be zero, the only safety for the produce in the car is the heat that is in the produce. If the produce is at 60 degrees and the outside temperature is at zero, you simply have a container which prevents that heat from leaking out down to the point where the produce will freeze. Now, if you put into the car, right in with the produce, ice which is possibly 32 degrees, you are throwing away the side of the container, so to say, and allowing your heat to flow immediately away into this cold, which is represented by the ice. It is simply an attempt to carry water in a pail by stripping off the sides of the pail and leaving the bottom there. That is the way it looks to me.

Now, the fact of the matter is that refrigerator cars are all built for warm weather; that is, they are all designed with ice bunkers to carry perishable fruit or products and to prevent those perishable products from decaying in a rising tempterature. If the car builders have any definite ideas, that is the only definite idea they have. In the larger and more important refrigerator lines, those going to California, that idea is present entirely in the minds of the car builders. In the winter time they leave out the ice and send the produce forward under ventilation. They open the ventilators to keep the fruit from spoiling. The fruit itself, when it is in process of ripening, provides quite a large amount of heat, so that, in a sense, provided the exposure is not too great, it carries along its own heating process, you might say, or heating machinery. Now, what Mr. Starr says is absolutely true. The men who build refrigerator cars are mechanics, who do not understand, even remotely, any of the theories or any of the principles of refrigeration or insulation, either. For example, nearly all the car lines running south from New York do not care for *any* insulation, because they say they run through warm climates. Now, of course, they run into quite serious changes of temperature, but they seem to be willing to take their chances on paying damage claims rather than paying for adequate equipment. It is an almost hopeless task to try to induce the railroads to pay for

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an adequately insulated car. Perhaps some time in the very remote future they will do it, but it seems to be far away.

Now, with reference to tests of the insulation value of refrigerator cars in service, I beg to say that I have had some experiences in my humble way along this line. I have made several journeys with refrigerator cars, one involving a trip from Chicago to the Pacific Coast and return, traveling in freight trains and suffering much inconvenience, if not actual hardship, in the cause.

The results of these investigations are published in a pamphlet by the Union Fibre Company, entitled "Insulation of Railway Equipment," beginning at page 67. Beginning at page 87 is a report of the Pacific Coast journey to which I allude, and on which the interior temperatures of the cars were taken by self-recording thermometers, or thermographs. The temperatures of the fruit were taken by a series of thermometers inserted in different oranges in boxes in different places in the cars. The outside temperature was taken every hour during the period of ten days. Any of our members who are interested in this subject can obtain these reports upon request.

I was hoping to get some personal expressions from some of the railroad men, so that you could see for yourselves just what they believe about this and how widespread this belief is. It is the most peculiar obsession that I have ever known. I don't know how it got started, but it is universally held by men who operate refrigerator cars.

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No. 110

Discussion of the Topic—LOSS OF REGRIGERATION AT DOORWAYS OF REGRIGERATED ROOMS.

S. P. Stevenson.—I suppose the loss of refrigeration at the doorways might be classified under two heads: One would be transmission of heat through materials, the same as through walls, assuming that the door is tight, and the other would be that loss of heat which would result from leakage, such as a bad fit or the door being more or less ajar. The only thing that occurs to me in the nature of a solution of the problem is as to how that loss would be affected by the increase in the velocity of the escaping air at different temperatures. The only thing I have heard that approaches a scientific explanation of the matter is that in a doorway or other opening 30 inches high the difference in the weight of the atmosphere at the top and at the bottom is so slight that no perceptible current will result from the aperture standing open. I suppose that would be considerably affected by the temperature and could hardly be considered exactly true. If, for example, there were no appreciable movement at 90 degrees, at a temperature of 60 degrees there would probably be considerable. There would be more flow of air at 32 degrees, and a vast deal more at 0 degrees.

President Shipley.—In connection with this door of 30 inches—you mean that the space that opens into it is 30 inches high?

S. P. Stevenson.—My understanding would be that it would be as true if there was a door at the bottom, at the floor, in a room of 30 inches in height, as if the room were 10 feet in height, or if the door were 3 or 4 feet or more from the bottom.

President Shipley.—Would it make any difference where that door was placed?

S. P. Stevenson.—I do not see why it would, if the velocity of the escaping air was based upon or controlled by the difference in its weight in a height of 30 inches.

President Shipley.—I suppose we will have to admit that the door is opened, but can't you tell us what is usually allowed for door surface? Don't you have some constant, some value for door sur-

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faces or for jambs of doors, leaving out the question of the insulation, or assuming it properly insulated?

S. P. Stevenson.—Do I understand you to refer to the transmission of heat through the door?

President Shipley.—No, I mean the crack of the door; I want to know if there is any loss to be considered in connection with a doorway in refrigerated spaces?

S. P. Stevenson.—I know of no constant; I have never heard of anything like that; I have been seeking something of that kind, but have not been able to find anything.

Conrad H. Young.—I think I can give an illustration that would show that this question is rather pertinent to small rooms, but when you get to very large rooms it doesn't amount to much. I had some experience in dealing with a room ten feet square and ten feet high, and that room, on an actual record of temperature, did not vary over a quarter of a degree. That room had at one corner a refrigerator door, I think, about two feet six inches by six feet, and we would find by just merely opening the door and running into the room and then running out and shutting the door, within a minute, with forced air circulation, the temperature would rise from two and one-half to three degrees by actual test record. I think you all know that just the minute you open a door to a refrigerated room of low temperature, especially on a humid day, you can see the effect of air circulation at once by the fog that will rise up; but if we are dealing with one door in a large room, say, approximately, 150 feet deep by 90 feet wide, it would not affect the temperature noticeably; whereas, in a small refrigerated room, such as butchers use, there would be a good deal of effect, especially if it were opened frequently.

Eugene W. Lewis.—The escape of air in volume, I think, would be the same in either case, but its effect would be governed by the relation of the size of the opening to the size of the room.

John L. Plock.—In general cold storage rooms we do not pay much attention to the heat losses through the doors, but it is very important and cannot be neglected in dealing with refrigerators for hotels, restaurants or domestic uses; the average small box, from three by six feet by five and one-half foot inside dimensions. For this kind of box it has been my practice to allow fifteen per cent. of the total B. t. u. radiation through the walls, bottom and top of the boxes for losses through the doors. I have found this to be a good average, and it has given excellent satisfaction in a great many actual cases in small refrigerators for general hotel use, where the doors

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are being constantly opened and very often left open for considerable time.

F. E. Matthews.—The fact that the door is overlooked in large cold storages does not mean that it is not of importance. I was at one time connected with one of the large Western packers. They had twelve boys whose business it was to do nothing but open and shut refrigerator doors. There they considered it important. It might be possible to arrive at a means of calculating air losses in the same way they get the amount of gas that flows up a chimney. I don't remember the formula, but it involves the difference in pressure resulting from the difference in temperature, which, as Mr. Stevenson says, might not be anything very noticeable in a one-story room, negligible in a case of a door 30 inches high, but might be considerable in the case of cold storage warehouses as they used to construct them without air locks. In such a case I have seen the air rush across the street, hit another building and go up 15 or 20 feet, much as water would if released through the same door under the same head.

John L. Plock.—In large cold storage rooms they generally have an entry room, or passageway, whereas with a hotel or restaurant refrigerator a great many of the boxes are almost constantly in use; for instance, for chef's order box, where the box will be continually opened and shut for perhaps two or three hours. I know of other engineers who are using this fifteen per cent. of the total heat transmission through the walls of the boxes as a constant for the door losses, all of whom, apparently, find it very satisfactory in reduction to practice.

Local conditions will almost always govern the case, and it might be necessary to increase this constant. No doubt we have all come across cases where, under almost the same conditions, it was necessary to put almost twice as much piping in the same size refrigerator to get equal temperatures, not because the insulation was poor, but because the location of the boxes governed the conditions, and also the personal equation of those having access to the boxes, one man being very careful to keep it open as little as possible, another being careless and indifferent as to the length of time the door was opened.

Conrad H. Young.—I would like to state that in making that comparison I did not mean to infer it was of no importance in connection with large rooms. I would like to state that I believe if you would go in a room 90 feet wide by 150 deep and keep the door open

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the same length of time you would in a small room, that you would not notice any sensible change in the temperature of the room unless that door were kept open constantly. To prevent this fault we have air-locks in the larger rooms and attendants to keep the doors shut.

President Shipley.—I think we all realize that while a large room is not affected as quickly, the effect is there; it has more of a cold reserve, and while the loss might be identical, the per cent. of the reserve loss would not be so great, and the loss would, accordingly, not be so perceptible as in small rooms.

S. P. Stevenson.—I might say that there are very important economies that can be achieved, and at no serious expense, by having what is known as a batten door with spring hinges to close it. That door can be knocked open by a truck going in either direction, and the loss is then very little more than just what air might pass through while the door is open. The leakage from the escape of air would thus be confined entirely to the time the door was held open by the passing truck, and even though that door is not made tight, the loss still would be very immaterial.

President Shipley.—That, in a measure, would be an ante-room, would it not?

S. P. Stevenson.—It would, but that door might be set on the inside of a wall, not more than eight to ten inches from the principal door.

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No. 111

Discussion of the Topic—THE BLOCK COUNTER CURRENT AMMONIA CONDENSER.

Louis Block.—The new condenser, which I first installed about eighteen months ago, was an accidental discovery. It depends apparently, upon the capacity of liquid to receive and impart heat more rapidly than gas. I allowed the gas to enter the bottom pipe of the condenser and discharge the liquid at the top. The condensation begins at about the fourth pipe from the bottom. The liquid mixes with the gas and travels upward together with the gas, which it does very easily, owing to the great velocity with which the gas enters the lower part of the condenser, due to the true counter-current principle. The gas wants to reach the upper pipe, where the water is coldest, presumably, and if it were not for the friction in the pipes there would be a very much lower pressure in the upper pipe than in the lower. The difference in the pressure is equalized, owing to the friction of the gas and liquid in the pipes. The thing is simply this (drawing a diagram): The gas enters here; the liquid discharges there, and the temperature of the water here is, say, 66 degrees, and down here, 80 degrees. Now, it must be presumed that the pressure in the lower pipe, or in the lower three or four pipes, would be that corresponding to the temperature of 80 degrees, or perhaps 10 degrees higher than 80 degrees, to account for the difference of temperature inside and outside of the pipe. In the upper pipe the pressure should be that corresponding to 60 degrees, or, again, 10 degrees higher, say to 70. The gas, therefore, rushes up there with a tremendous velocity, and, since there is little trouble in overcoming the weight of the liquid, it is moved upward ahead of the gas and discharged here.

In order to prevent any accidental discharge of gas, a trap is placed there at the top. I have always, in order to equalize the pressure in a number of condensers, arranged an equalizing header here, but, since this would form a syphon, I put on a syphon breaker and connect it with the equalizing header, and if I want to empty any condenser I do it through this. The temperature of the liquid

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discharged is within from 5 to 8 degrees of the temperature of the water. I have seen it as low as within 4 degrees of the temperature of the water. I have seen records, shown me by Mr. Shipley, in which it was even lower than that. The advantage is that a lineal foot of pipe in this condenser will do very much more work than a lineal foot of pipe in a condenser in which the exchanges of heat is from a gas, ammonia, to a liquid, water.

We know that the exchange of heat from a gas to a gas is 3 B. t. u.'s, from a liquid to a gas is 60, and from a liquid to a liquid is 300 B. t. u.'s. In other words, this condenser, if full of liquid, should do five times as much as the ordinary condenser. Since it contains a mixture of liquid and gas together it does three to three and a half times as much as any other condenser, so that, with 9 lineal feet of pipe, it is possible with 60-degree water, to do a ton of refrigeration. There were some other things that I had to pass through in order to reach the form shown here. It was a discovery, not an invention.

N. H. Hiller.—I would like to ask Mr. Block if he had a pressure gauge on both the liquid receiver and also on the inlet, and what was the difference in pressures?

Louis Block.—They're exactly the same: I had a pressure gauge on the liquid outlet and the hot gas inlet. The liquid receiver stands usually in a warm engine house, and any vapor which might form in it can pass back into the condenser by means of this small pipe, which connects with the equalizing header.

Henry Torrance, Jr.—Mr. Block, you said you generally throttled that inlet pipe. If that is the case, those gauges must be different.

Louis Block.—Yes, but it is not. If the inlet is a two-inch pipe, the valve is left one-half turn open; that means that the valve is 1-16 inch away from the seat. I have one condenser where I tried to determine exactly how large the opening should be, and I inserted various cones. I found that a ⅜-inch opening is quite sufficient for 35 tons of refrigeration in the condenser.

Henry Torrance, Jr.—But the pressure gauges would indicate differently?

Louis Block.—They do not.

Henry Torrance, Jr.—They must.

Louis Block.—They must not. If the proportion of a two-inch pipe to that opening is as 1 to 50 and the speed beyond this opening or through that opening is 50 times as great as it is in the

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two-inch pipe, then it must not, and that seems to be the case. That was a thing which I had to learn by experience. The first condensers which I erected had 54-degree water. I left this valve wide open, and I found that about two and a half or three condensers, because the one was only warm up to about half its height, could do the work of about 100 tons of refrigeration. When I came to use 89-degree water I wanted to divide the work among more than three condensers. I wanted to put it into four condensers, because I found that the water did leave the condensers at 105 degrees, and I wanted it lower. I showered 60 or 65 gallons a minute over each one of these coils, and, in order to divide the work, I began to throttle. I first shut off one turn, and finally I had all the valves only one-half turn open, and then found that I could divide the work among the four condensers; if I left them open, three condensers would do the work; if I started up another 100-ton machine, three more condensers would go into action. I couldn't get any more into commission; the rest would be stone cold. The condensers nearest the hot gas inlet got the gas. If you take steam at a pressure of about 60 pounds and blow it through a 1-inch pipe a foot long, letting it expand down to the atmosphere, you would get a velocity of 2,500 feet a second. The difference in pressure in this case is dissipated in overcoming the friction in the pipe. For the same reason the pressure gauges indicate the same pressure in the hot gas header as in the liquid pipe.

Charles H. Herter.—In your condenser are not the lowest four pipes enlarged from 2 inches to 2½ inches?

Louis Block.—No; in the first ones built the lowest four pipes are larger. I thought it would be a wise thing to do, but I found it was not necessary. A desirable thing to do is to have dams in the return bends; that is, I form the return bends in this wise to insure the pipes being always partially full of liquid. I wanted to get the mixture of liquid and gas, and for that reason I adopted that plan. This means that if you empty your condenser, the liquid will not all go down into the lower pipes, but will be divided among all the pipes, so that if you start the condenser any moment there will be no shock. As I have it, the gas will be pumped directly into a layer of liquid. I also provide drains connecting into a drain header, so that when I want to stop the condenser I can shut the inlet valve, open the drain valve and let the liquid drain out of the pipes, which have the ordinary return bends. Where the return bends with dams are used it is not necessary.

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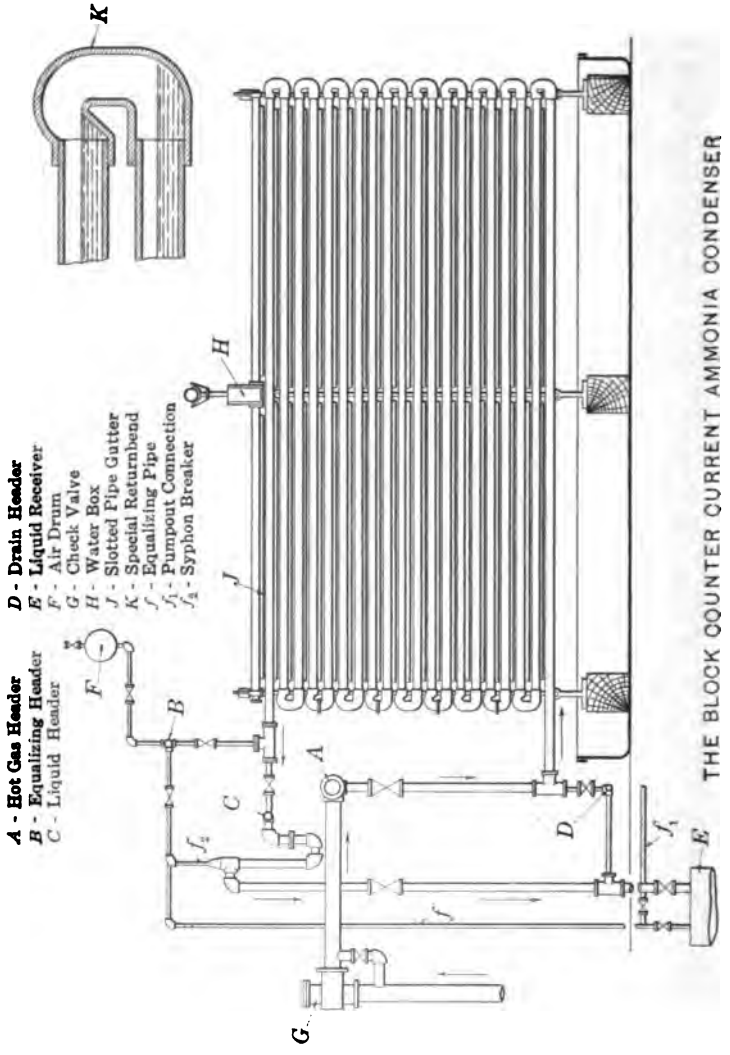

THE BLOCK COUNTER CURRENT AMMONIA CONDENSER

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Theodore Kolischer.—I would like to ask if you will not obtain equal results from water at high temperature from the top part?

Louis Block.—Yes, you get as good results as from any condenser I know of. The last installation was a plant in St. Louis, where they had water of 98 degrees. They had three cooling towers, but two went out of commission, because something happened to the fans, so they were only using one tower, and the initial temperature of the water was 98 degrees. They kept right on making 300 tons of ice, showered a very large quantity of water over those condensers, and the temperature of the water as it left the condensers was 103 and the pressure was 210.

Edward N. Friedmann.—Did you make any experiments as to the number of pipes?

Louis Block.—I have used 16, 20 and 24 pipes; for warm water I advise 20; for cold water 16 to 18.

Edward N. Friedmann.—The temperature corresponds to the water running off?

Louis Block.—We take the temperature of the water as it leaves the lower pipe, add 5 degrees and look in the table for the pressure which corresponds to that temperature. That will be the pressure indicated by the gauge on the hot gas header.

Henry Torrance, Jr.—Do you figure that when you close or throttle that inlet valve you get just as good a head pressure as though the whole thing were left open and the gas had free access?

Louis Block.—Yes.

Henry Torrance, Jr.—In other words, where you throttle, the pressure of the gas changes into velocity?

Louis Block.—Exactly.

Henry Torrance, Jr.—There must be a little wiredrawing there which would cause some loss, anyway.

Louis Block.—And still the gauges don't show it.

John E. Starr.—I would like to ask one question. I understand the reasoning that has been used in connection with the compression machine, but suppose you were running an absorption machine and desired, by the use of more water, to get a lower pressure, wouldn't that possibility be somewhat limited? How about running the water through a smaller range? That is, instead of 60 to 80 degrees, why not run it from 60 to 70? In this particular form, wouldn't there be a limitation of the amount of water you could use on account of the length of the trough?

Louis Block.—There is, of course, a limit, but as I stated a few

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moments ago, in this St. Louis plant, they heated the water only 5 degrees, and this is the way I do it: I have a water box which is 12 inches high, and a 2-inch pipe with a ⅜-inch slot. The water flows in through an inch and a half pipe. I let the nipple come to the edge of the water box. I don't stick it inside. Now, the box fills about half full of water, and I get a flow so that I can shower 65 to 70 gallons per minute. Somebody claimed 75 gallons. I have only done 70 per minute over such a condenser. Now, I can figure what work the condenser must do. There is another way of designing a gutter which will shower still more water, but when you shower 75 gallons over, and stand by that condenser, it seems to flow over the condenser about a quarter of an inch deep. It is very easy to put enough water over a condenser to heat the water 13 or 13½ degrees, so that you would need 2 gallons for a ton of refrigeration per minute, but when you want larger quantities, so as to heat the water not more than ten degrees, you must have special appliances; you must have this, at least, if you can't find anything better. The ordinary present mode of overflowing gutters or a gutter with perforations will not give enough water.

John E. Starr.—What I wanted to get at is this: Suppose you had a condenser giving you 50 tons of refrigeration at a certain pressure, using a gallon and a quarter of water per minute per ton of refrigeration. With the water coming in at 60 degrees and going away at 80 degrees, making a range of 20 degrees, you will get a resulting head pressure of 165 pounds.

Louis Block.—What initial temperature did you say?

John E. Starr.—In at 60 and coming out at 80.

Louis Block.—About that.

John E. Starr.—Now, then, suppose, with the same apparatus, by the use of about twice as much water, you desired to run that pressure down to 125 or 130 pounds. Would it be possible with the same apparatus to get the same tonnage, this original 50 tons, out of that condenser?

Louis Block.—I don't see any reason why you shouldn't. I don't see that it makes any difference at all.

John E. Starr.—That is, you think you could utilize successfully double the amount of water on the condenser without wasting it?

Louis Block.—Yes, I have experimented with water as low as 54 degrees and as high as 84½ or 85, and with water at 84½, I did, with such a condenser, 18 pipes high, 56 tons of work. The

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water was heated from 84½ to 103 degrees. I could not shower more water, over, than I did at that time, but, you see, it was very high temperature water; even 84½ degrees is high. When you have water of 60 degrees you can shower enough over so it will flow off at 70, at a rate of 2½ gallons per minute per ton of refrigeration per day.

John E. Starr.—Over a pipe how long?

Louis Block.—Twenty feet long. That is, the slotted pipe is 10 feet long, the box is in the center, and the slotted pipe gutters go out each way. The water divides and flows in both directions.

John E. Starr.—I am asking the question because it is important in low temperature work, where we desire a lower head pressure. If we have 60-degree water, under many conditions, we don't want that water to go away much over 70, so that we may get a pressure of not over 125 or 130 pounds.

Louis Block.—Mr. Torrance is going to put up a number of condensers eight pipes high. He is very liberal with his condensing surface. I don't think he needs it, but he wants to do 300 tons of refrigeration, and figured out for himself, knowing what I have done with these condensers, that eight pipes would be safe. I am sure that he will not heat that water more than 5 degrees, and that with each 8-pipe section he will do about twelve or perhaps fifteen tons of work.

John E. Starr.—At what head pressure?

Louis Block.—The pressure will correspond to the final temperature plus 5 degrees. If he has 60-degree water he will have a pressure which corresponds to 70 + 5, or 75 degrees.

Henry J. Torrance, Jr.—I understand you can distribute about 65 gallons of water a minute over a 20-foot trough?

Louis Block.—Yes, 75 gallons.

Henry Torrance, Jr.—I think you are pretty smart.

Louis Block.—I know I am. (Laughter and applause.)

President Shipley.—Mr. Torrance does discover something every once in a while.

Edward N. Friedmann.—You haven't tried it on a double pipe condenser?

Louis Block.—I haven't tried it on a double pipe condenser, but it would be the same thing.

Edward N. Friedmann.—Except that you could squeeze more water through with a pump.

Louis Block.—I don't believe it.

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V. R. H. Greene.—I would like to ask Mr. Block a question; have you any test to show in how many pipes complete condensation takes place?

Louis Block.—No, I haven't. I have rigged up a condenser for that purpose, but has as yet never made the test.

V. R. H. Greene.—Would complete condensation take place up to and including 12 pipes?

Louis Block.—Yes, I have done the work with 12 pipes, but it is difficult to determine just where it began. I assume from the temperature change of the water that it starts actively in the third pipe from the bottom, because the increase of the temperature in the two lowest pipes is very little.

V. R. H. Greene.—Then you use the upper pipe as the liquid pre-cooler?

Louis Block.—I use the upper two pipes as a liquid cooler. When I start the condenser I put my hand on the liquid pipe, and if the liquid comes away warm I throttle the gas valves until it comes away cold; then I leave it at that. I find that a ⅜-inch opening in the gas valve is about enough.

Irving Warner.—Where is a good place to drain off inert gases?

Louis Block.—You mean non-condensible gases? I do this: I connect a drum 6 inches in diameter and 6 feet long above the equalizing header, and I connect to the top of it a blow-off pipe. Any air or non-condensible gases in the system will go automatically into the drum. Any time I want to blow it off I shut the valve to the condenser and open the purge valve.

Henry Torrance, Jr.—I am still from Missouri on that gauge question. I think if you had accurate gauges, such as you used to talk about on the suction side of your ice machine, you would see a little difference there.

Louis Block.—I haven't been able to see it.

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No. 112

Discussion of the Topic—THE SHIPLEY AMMONIA CONDENSER.

President Shipley.—Mr. Block said that his condenser was the result of an accident; my condenser was the result of being spurred by Mr. Block, so that I think that I am part of that accident, too. I had an idea, but it lay dormant and I didn't do anything with it. It just stuck in my brain until I found out what Mr. Block was doing, and so it was time for me to get busy, and I got busy. The idea I had in mind was to take a shell, Figure 1, a closed condenser; with tubes A, I bring the water in at B and let it overflow at C. At D there is a connection, and with an ejector here at E, with a pipe connecting it to F. The gas enters at G and the liquid is taken off at H. I believed that ammonia could be condensed the same as steam is condensed in a jet, or barometric condenser, and I built the apparatus as shown in Figure 1. It was so easy that I felt like kicking myself. Then the result was that after experimenting with this sort of an apparatus I tried to get something into pipe form. I eventually accomplished the same thing by connecting up a coil as shown in Figure 2, putting the ejector at E. The gas came in at G, and I took the liquid off at H. I put a trough on at I, from which the condensing water was sprinkled over the coil. This apparatus worked as well as that shown in Figure 1. The liquid ammonia entered the ejector through the connection D, and the resultant liquid was driven up into the top pipe of the coil at F, whence it flowed down through the coil, where it was cooled by the water flowing over it. At H part of the liquid was drawn off to be used in the general system, and the remainder passed on to repeat the cycle.

Mr. Block said he got 60 and 70 gallons of water over a condenser of this type. There's no question about getting 60 or 70 gallons of water over a 2-inch pipe condenser 20 feet long. We ran 72 and 75 gallons over the coil when we wanted to.

Our first tests were made on a small plant having a capacity of about 25 tons' refrigeration. This was not large enough to make

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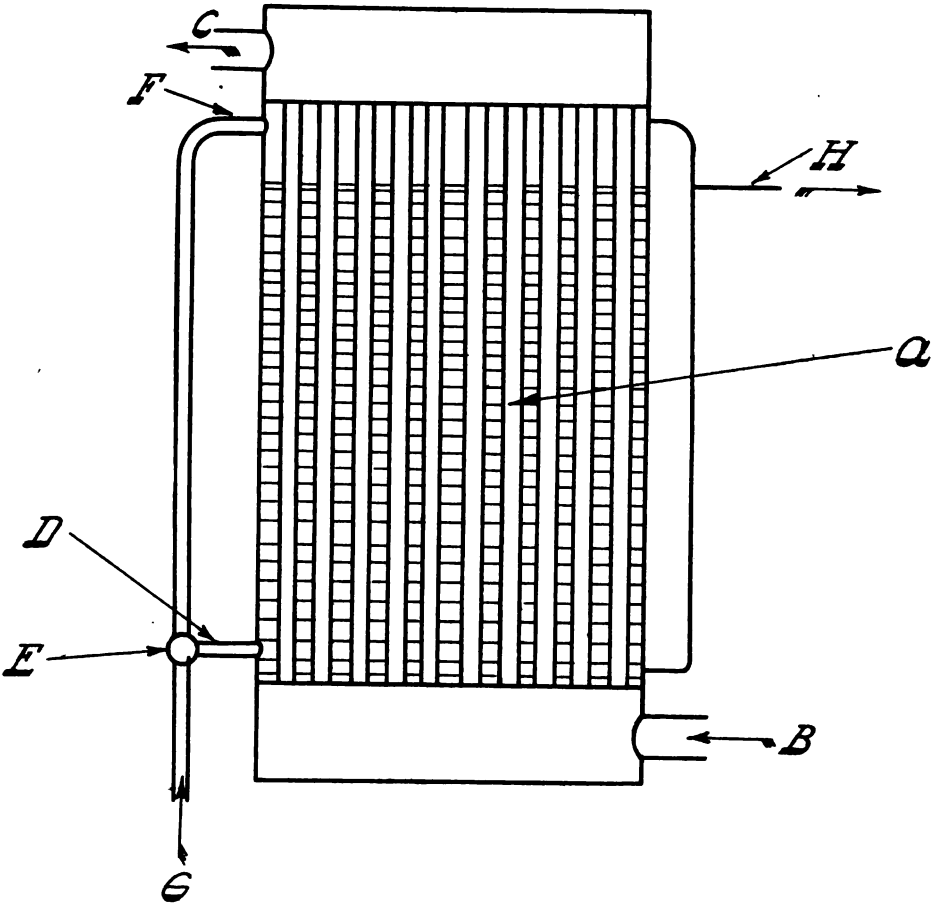

FIG. 1.—SHIPLEY FLOODED AMMONIA CONDENSER, SHELL AND TUBE TYPE.

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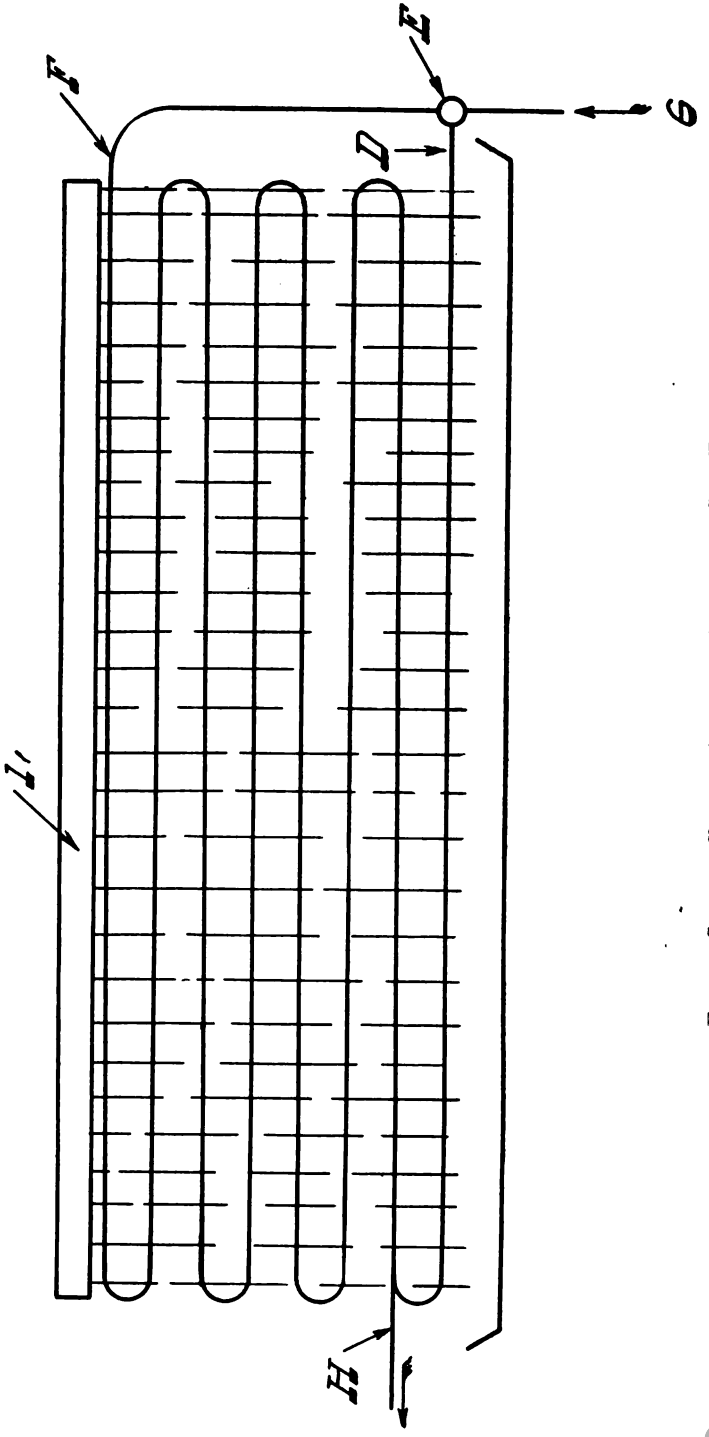

FIG. 2.—SHIPLEY FLOODED AMMONIA CONDENSER, COIL TYPE.

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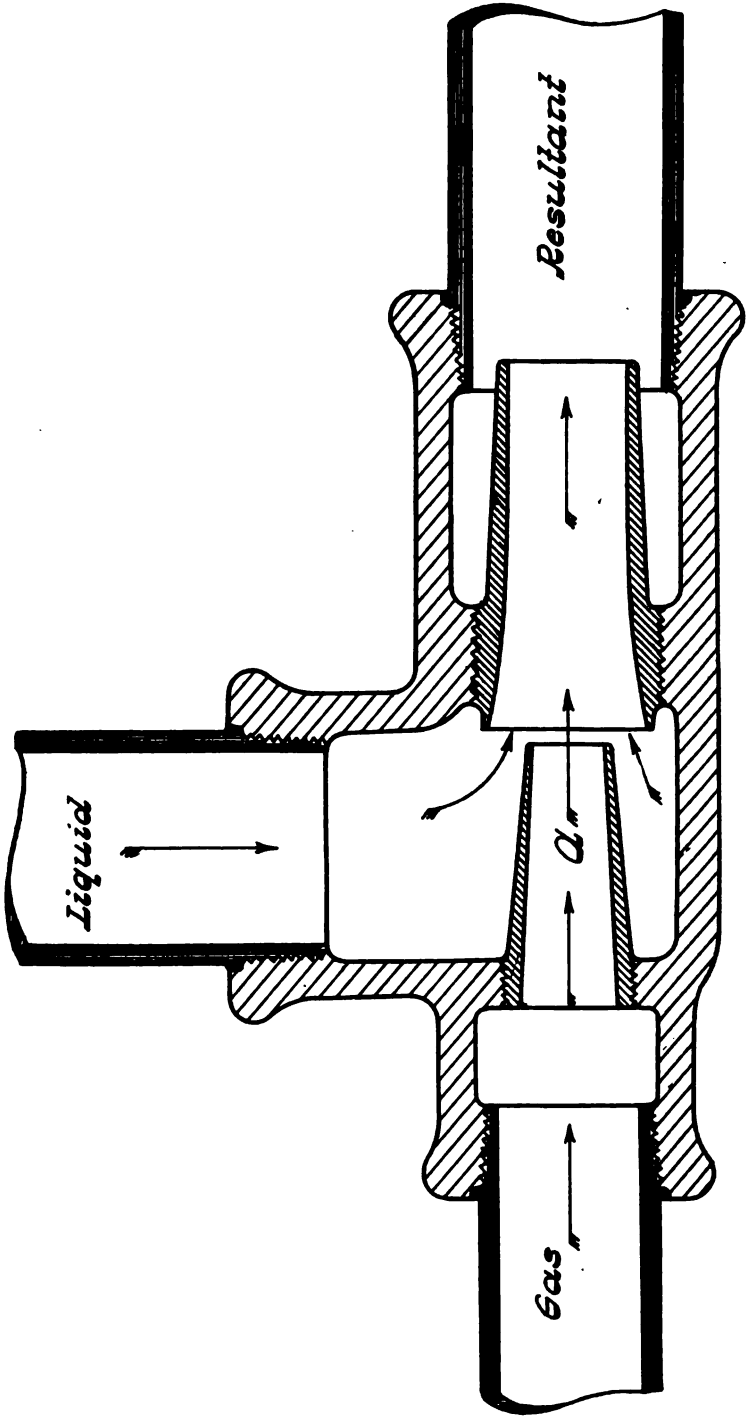

FIG. 3.—EJECTOR ON SHIPLEY FLOODED AMMONIA CONDENSER.

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the determination we wanted, so I had a 100-ton machine and plant put up, and we are using that now, running three shifts a day. Up to date we have made 106 runs, and we will be at it for some time to come. We have experimented on coils from 20 pipes high down to 6, and have, so far, found 10 pipes high to give us the maximum efficiency per square foot of surface. We have also experimented upon the apparatus by putting in a section of two pipes under the main coil, through which the gas was passed before it entered the ejector, thus removing the sensible heat from the gas before it met the liquid. This gives us 150 square feet of surface in the total twelve pipes.

We have experimented with a number of ejectors, both as to size and shape. The one we are using now is shaped as shown in Figure 3. The nozzle which we have found to be most effective up to this time is ¾ inches in diameter at A.

We are getting capacities and pressures for 35 gallons to 75 gallons at temperatures varying 5 degrees from 55 to 95 degrees, with pressures from 100 to 225 pounds. When we get through we will have tables to show all practical pressures for each volume and temperature of water between the ranges mentioned. These tables will give Mr. Starr the information he requires for absorption machines and will also give data to determine the commercial possibilities where water, coal or first cost is the prime consideration. As to the capacity to be given out of this type of condensers, will say that with a ten-pipe coil, having two pipes to take the sensible heat from the gas, each pipe being made of 2-inch standard pipe 20 feet long, gives 150 square feet of effective cooling surface. Such a coil being showered with 50 gallons of water per minute at 85 degrees initial temperature will condense enough gas to do the work of 25 tons' refrigeration per twenty-four hours. That would mean two gallons of 85-degree water per minute per ton of twenty-four hours.

Figure 4 will show the coil I have described. You will note the ejector at E. This form of condenser allows hot liquid to be somewhat cooled before it passes up to the top of the condenser. The pipes a-a perform the preliminary cooling work.

N. H. Hiller.—What is the temperature of the outlet water?

President Shipley.—The final temperature of the water is 97 degrees. We figure out that we get about 24.4-gallon degrees.

N. H. Hiller.—There are 10 pipes in the condenser above the

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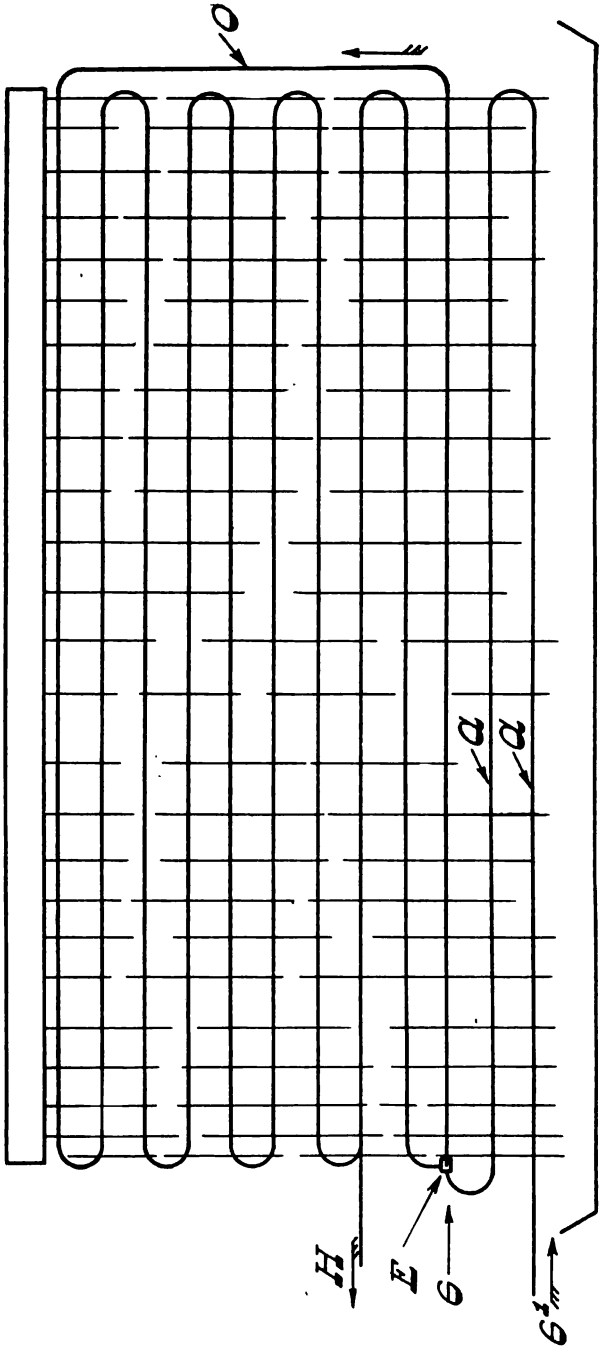

FIG. 4.—SHIPLEY FLOODED TYPE AMMONIA CONDENSER, SHOWING GAS PRECOOLING COIL a-a.

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ejector, two of which drain into the ejector, and you use a preliminary cooler of two additional pipes below.

President Shipley.—We figured on a 10-pipe condenser and then put this 2-pipe preliminary cooler underneath.

John E. Starr.—It would seem that there is some little conflict between Mr. Block's statement and your statement as to the square feet of surface per ton when you reduce the temperature of the water.

President Shipley.—Mr. Starr, this is not the same proposition as Mr. Block's. You understand, we are not running this on the same principle as Mr. Block's.

John E. Starr.—I understood Mr. Block to say that with double the amount of water off of the same apparatus we could get the same tonnage at a reduced pressure.

Louis Block.—You can.

John E. Starr.—I understand Mr. Shipley to say that, as far as his experiments go, you get a reduced tonnage.

President Shipley.—We got 21.6 tons from the coil I have described, with 85-degree water and running 35 gallons per minute, with a head pressure of 205 pounds. That gave us 1.65 gallons of water per minute per ton.

John E. Starr.—But the tonnage was reduced?

President Shipley.—The tonnage was reduced with reduced water.

Eugene W. Lewis.—What is the temperature of the water going off at 35 gallons?

President Shipley.—99.28. You see, water running over a condenser is not even. I mean the temperature at one point may not be the same as the temperature at another point: hence it is quite difficult to get the exact temperature of the water at the different parts of the condenser. For this reason the temperature of the water in the overflow is not constant.

Charles H. Herter.—Will you kindly give us the rate of flow of the gas through the pipe to the condenser?

President Shipley.—I cannot tell you the rate of flow. I am only telling you just what happened. We have not had time to analyze the work done by the condenser; hence I can only give you the figures.

John L. Plock.—I do not quite understand that ejector arrangement. Am I correct in assuming from the diagram that the gas

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goes to this ejector first or that the gas is condensed partly in the condenser before it goes to the ejector?

President Shipley.—The ammonia comes in at G, Figure 4, in the gaseous form. We know by its temperature that no liquefaction takes place in the preliminary section, but most of the heat of compression is removed.

John L. Plock.—Then the ammonia comes to the ejector in the form of a gas?

President Shipley.—It is in the form of a gas at point G, Figure 4.

John L. Plock.—Then how does the tonnage increase by the aid of this particular ejector?

President Shipley.—I cannot say how the tonnage is increased, but I can say that the condensation is effected in a similar manner to that of a jet or barometric steam condenser; at least, that is the way I see it. The figures I have given show what the result is.

John L. Plock.—I had hoped to have some data here on a battery of condensers of the "Block" flooded type, which were built by the Ruemmeli-Dawley Manufacturing Company and erected at Panama. These condensers took the place of double pipe condensers that had given a great deal of trouble from corrosion, and to overcome this I had recommended the atmospheric condensers. Their operating engineer wrote me that five condensers of Mr. Block's flooded type were liquefying gas equal to 200 to 220 tons of refrigeration, which, as you will notice, is 40 tons and over per stand of condensers twenty-two pipes high, twenty feet long, and all this under the unfavorable conditions of using water at 80 degrees Fahrenheit.

V. R. H. Greene.—Is the flow up the pipe marked O?

President Shipley.—Yes, the ammonia goes up pipe O.

V. R. H. Greene.—Then you drain the liquid off at the other end?

President Shipley.—We drain it off at H.

V. R. H. Greene.—Can you keep enough liquid down below that to feed the ejector?

President Shipley.—Yes. At first I expected trouble from that source, but we found none at all after trying the apparatus out. We tried it at every bend, at every level, from top to bottom, and the only difference we found was in the temperature of the liquid leaving the coil; the lower the connection, the cooler the liquid going to the receiver.

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Peter Neff.—Isn't it probably a fact that those top coils are full of liquid in very much the same condition as exists below?

President Shipley.—I believe from the temperatures we get up here at the top pipe that it is filled with part liquid and part gas.

Peter Neff.—Is the heat transmission necessary for condensation between liquids on either side of the metallic wall?

President Shipley.—As far as we can get at it, the condensing is done at the ejector, and it goes up pipe O as liquid, which is afterwards cooled coming down through the coil. There is some gas in the top pipe, but whether this is non-condensible gas or ammonia gas, which has come over with the liquid, we have been unable to determine so far.

Peter Neff.—Then you have a chance to take the heat out by liquid contact against the walls?

President Shipley.—Yes. The liquid practically fills the coil, except as I have explained, from the ejector back to the inlet. We know this by the temperatures within the pipes. You cannot hold gas below the critical temperature due to the pressure.

Theodore Kolischer.—I would like to ask Mr. Shipley as well as Mr. Block whether their types of condensers could be applied to condensers of other makes already in existence?

President Shipley.—I don't think you need us to tell you that, Mr. Kolischer. We can tell you "Yes, sir," if that does you any good. You want to get us on record; is that it?

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* Dawley, C. W. (1912), McAlester, Okla.

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§ Forgy, John E. (1912), Charles Warner Co., Wilmington, Del.

Fowler, A. M. (1910), United Iron Works, 151 North Los Angeles street, Los Angeles, Cal.

Frantz, Samuel R. (1905), 219 West Main street, Waynesboro, Pa.

* Freeland, Arthur G. (1912), Bernheimer & Schwartz Pilsener Brewing Company, Amsterdam avenue and One Hundred and Twenty-eighth street, New York, N. Y.

Frick, Ezra (1904), (Director), Clayton avenue, Waynesboro, Pa.

Friedmann, Edward N. (1904), (Director 1910, President 1911, Director), 90 West street, New York, N. Y.

Gallenkamp, Jr., Edward W. (1911), St. Louis Refrigerating & Cold Storage Company, St. Louis, Mo.

Gardiner, Edward J. (1906), Harrow road, Bexley, Sydney, New South Wales, Australia.

Geisler, George H, (1909), United Iron Works, Second and Jefferson streets, Oakland, Cal.

*Golden, Albert J. (1908), Industrial Cold Storage & Warehouse Company, American and Berks streets, Philadelphia, Pa.

Goodmanson, Frank A. (1907), La Plata Cold Storage Company, Ltd., Pureto La Plata, Argentine Republic.

Goosmann, J. C. (1904), 172 Washington street, Chicago, Ill.

Gray, John Lathrop (1909), Tide Water Oil Company, East Twenty-second street, Bayonne, N. J.

Greene, Van Rensselaer H. (1905), De La Vergne Machine Company, foot of East One Hundred and Thirty-eighth street, New York, N. Y.

§Guckel, Charles H. (1906), Springfield Gas & Electric Company, Room 2, Woodruff building, Springfield, Mo.

Hague, John (1911), 1228 Pine street, St. Louis, Mo.

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*Haire, David E. (1905), 2128 Land Title building, Philadelphia, Pa.
Hargreaves, William (1905), De La Vergne Machine Company, foot of East One Hundred and Thirty-eighth street, New York, N. Y.
*Hausmann, Carl (1909), 13 Featherstone Terrace, Wellington, N. Z.
Haven, Harry M. (1904), F. W. Dean, Inc., 53 State street, Boston, Mass.
Havenstrite, Charles D. (1908), H. W. Johns-Manville Company, 322 North Michigan avenue, Chicago, Ill.
*Herst, Franklin H. (1905), Twenty-ninth and Market streets, Philadelphia, Pa.
§Herter, Charles H. (1912), Ice Trade Journal Company, 116 Nassau street, New York, N. Y.
*Hexamer, William E. (1908), Vilter Manufacturing Company, 864 North Franklin street, Philadelphia, Pa.
§Hill, John (1911), Shipley Construction & Supply Company, 90 West street, New York, N. Y.
*Hill, Walter L. (1905), 110 State street, Boston, Mass.
Hiller, N. H. (1904), (Director 1909-'11), Carbondale Machine Company, Carbondale, Pa.
§Hoffman, C. E. (1907), 622 Beatty building, Houston, Tex.
§Hoffmann, W. John (1911), 1014 Washington street, Hoboken, N. J.
Holcombe, E. M. (1912), Carbondale Machine Company, Carbondale, Pa.
Holden, D. L. (1904), Viscosity Ice Machine Company, American National Bank building, Indianapolis, Ind.
*Hoos, William (1907), 143 North Front street, Philadelphia, Pa.
*Horne, Frank A. (1907), (Treasurer), 161 Chambers street, New York, N. Y.
*Horne, George A. (1911), 161 Chambers street, New York, N. Y.
§Horr, Leonard W. (1912), 131 Eighth avenue, La Grange, Ill.
Hoshino, Ichizo (1911), Takata & Company, Ichome Yurakucho, Tokyo, Japan.
*Hovey, Charles A. (1909), United Cork Companies, 50 Church street, New York, N. Y.
*Hughes, John L. (1909), Yakima Artificial Ice & Cold Storage Company, North Yakima, Wash.
Hunter, George C. (1907), 1392 West Third street, Cleveland, Ohio.
Irwin, Oliver C. (1912), Arctic Ice Machine Company, Canton, Ohio.
Jacobus, D. S. (1904), (Director 1905-'06, President 1907), Babcock & Wilcox Company, 85 Liberty street, New York, N. Y.
§Jaeger, A. P. (1908), 2122 California street, Omaha, Neb.
§Jamison, Jr., J. V. (1908), Jones Cold Store Door Company, Church and Foundry streets, Hagerstown, Md.
Jenks, L. Howard (1904), (Director 1905-'07), Frick Company, 39 Cortlandt street, New York, N. Y.
*Johnson, Albert (1906), 2635 Hampden court, Chicago, Ill.
Judd, Frederick F. (1912), 1136 Old South building, Boston, Mass.
*Judson, Horace H. (1912), H. W. Johns-Manville Company, Madison avenue and Forty-first street, New York, N. Y.
Karl, Robert H. (1910), 4620 Vernon avenue, St. Louis, Mo.
Kerbel, C. Joseph (1910), Central Consumers Company, Louisville, Ky.
Kilian, Justus (1907), Vilter Manufacturing Company, 872 Clinton street, Milwaukee, Wis.

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Kleucker, George M. (1912), 3951 West Belle place, St. Louis, Mo.
Kolischer, Theodore (1907), (Vice-President), Central Construction & Supply Company, 140 North Tenth street, Philadelphia, Pa.
Kremer, Waldemar R. (1907), Vilter Manufacturing Company, Milwaukee, Wis.
Krum, Charles L. (1904), 421 North State street, Chicago, Ill.
Laichinger, John (1911), 1214 Liggett building, St. Louis, Mo.
Lane, George H. (1910), Shipley Construction & Supply Company, 90 West street, New York, N. Y.
Langley, Frank W. (1911), United Iron Works, 151 North Los Angeles street, Los Angeles, Cal.
Levey, John (1904), (Director), National Machine Works, North and Sheffield avenues, Chicago, Ill.
*Lewis, Eugene W. (1907), 6053 Woodlawn avenue, Chicago, Ill.
§List, Leonardo J. (1908), 864 North Franklin street, Philadelphia, Pa.
*Livezey, John R. (1907), 1933 Market street, Philadelphia, Pa.
*Loney, Luxton (1906), Equitable building, Sydney, Australia.
*Long, E. L. (1911), Armstrong Cork Company, Powers building, Rochester, N. Y.
Louis, J. S. (1904), Triumph Ice Machine Company, Oakley, Cincinnati, Ohio.
Lucke, Charles E. (1908), (Vice-President 1910-'11), Columbia University, New York, N. Y.
§Luedicke, Alexander H. (1911), 1011 Richards street, Milwaukee, Wis.
Luhr, Otto (1906), 4024 Clarendon avenue, Chicago, Ill.
*Lynch, John H. (1907), 17 South William street, New York, N. Y.
MacDonald, M. S. (1912), C. A. MacDonald, Ltd., 542 Point road, Durban, South Africa.
Macintire, H. J. (1912), University of Washington, Seattle, Wash.
McCandlish, Robert M. (1912), 1217 Commerce building, Kansas City, Mo.
*McCarthy, George L. (1904), 116 Nassau street, New York, N. Y.
*McDaniel, Homer (1905), (Vice-President 1909-'10), Sheriff Street Market & Storage Company, 2235 East Fourth street, Cleveland, Ohio.
*McDougall, A. M. (1909), Northern Cold Storage & Warehouse Company, Seventh avenue, West, and Railroad street, Duluth, Minn.
§McKee, Thomas C. (1907), Carbondale Machine Company, 431 South Dearborn street, Chicago, Ill.
*McPartlin, Stephen E. (1905), 20 West Jackson boulevard, Chicago, Ill.
*McPike, Eugene F. (1909), American Railway Perishable Freight Association, Lord building, 1200 Michigan avenue, Chicago, Ill.
Manns, W. H. (1904), (Director 1909-'11), 219 West Second street, Waynesboro, Pa.
Markel, E. J. (1905), Room 30, 739 Chapel street, New Haven, Conn.
Marshall, A. T. (1909), 53 Oakland Terrace, Hartford, Conn.
*Marshall, Lewis C. (1905), 178 Devonshire street, Boston, Mass.
*Mason, Dale R. (1912), National Tube Company, 1810 Frick building, Pittsburgh, Pa.
Massa, R. F. (1912), H. W. Johns-Manville Company, Madison avenue and Forty-first street, New York, N. Y.

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Matthews, F. E. (1904), Leonia avenue, Leonia, N. J.
Mayer, Fred W. (1908), Mayer Ice Machine & Engineering Company, Jersey City, N. J.
*Meeske, William (1911), 700 East One Hundred and Sixty-third street, New York, N. Y.
Meltzer, Arthur (1905), 418 H. W. Hellman building, Los Angeles, Cal.
Miller, Edward F. (1910), Massachusetts Institute of Technology, Boston, Mass.
*Moore, Herbert (1907), 99 South Front street, Memphis, Tenn.
Moore, Hervey M. (1907), United Iron Works Company, Springfield, Mo.
Morris, O. J. (1905), Wilson building, Dallas, Tex.
Morse, Louis S. (1909), York Manufacturing Company, York, Pa.
*Morton, William P. (1907), Henry Bower Chemical Manufacturing Company, 2815 Gray's Ferry road, Philadelphia, Pa.
Neff, Peter (1904), (President), 406 High street, Canton, Ohio.
Neubecker, Jean (1908), 347 East One Hundred and Thirty-ninth street, New York, N. Y.
*Nickerson, J. F. (1904), 431 South Dearborn street, Chicago, Ill.
Nifong, Walter R. (1912), Commerce building, Kansas City, Mo.
Nolde, Fred (1908), 380 Bourse building, Philadelphia, Pa.
Nordmeyer, L. C. (1904), (Director), 1214 Liggett building, Eighth and Chestnut streets, St. Louis, Mo.
Nulsen, Herbert S. (1909), 90 West street, New York, N. Y.
Odermann, E. H. (1905), Frick Company, Waynesboro, Pa.
Palmer, C. C. (1904), Railway & Stationary Refrigerating Company, 11 Pine street, New York, N. Y.
Palmer, G. H. (1912), Railway & Stationary Refrigerating Company, 11 Pine street, New York, N. Y.
Parsons, W. Everett (1904), (Director 1905, President 1906), 818 Degraw avenue, Newark, N. J.
Patitz, G. J. (1909), Peter Schoenhofen Brewing Company, 526 West Eighteenth street, Chicago, Ill.
Penney, Edgar (1904), (Director 1905-'07, President 1908), Newburgh Ice Machine & Engine Company, Newburgh, N. Y.
§Petersen, Samuel (1912), Mechanical Refrigerating Company, 864 North Franklin street, Philadelphia, Pa.
§Phillips, E. A. (1911), Central Ice Company, Beach Haven, N. J.
Phillips, Ellis L. (1904), (Director 1905-'06), 50 Church street, New York, N. Y.
*Phillips, Louis A. (1909), Mitchell-Tappen Co., 149 Broadway, New York, N. Y.
Pilsbry, F. W. (1904), (Director 1907-'09), 1332 Monadnock building, Chicago, Ill.
Plock, John L. (1910), 30 Church street, New York, N. Y.
Pownall, H. D. (1907), Arctic Ice Machine Company, Canton, Ohio.
§Prell, John S. (1907), 1137 Geary street, San Francisco, Cal.
Pryor, Frederick L. (1911), Stevens Institute of Technology, Hoboken, N. J.
Qualtrough, B. F. (1911), 321 Reliance building, Kansas City, Mo.
*Quigley, James Edwin (1905), 466 South Rebecca street, Pittsburgh, Pa.

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*Rasbury, John A. (1912), 403 Walton building, Atlanta, Ga.
*Reilly, James P. (1905), 17 Battery place, New York, N. Y.
Rey Basadre, J. S. (1906), 569 Avenida Quintana, Buenos Aires, Argentine Republic.
Richardson, George P. (1911), Isbell-Porter Company, 46 Bridge street, Newark, N. J.
*Richmond, Herbert (1911), 90 West street, New York, N. Y.
Riley, William H. (1908), Remington Machine Company, Wilmington, Del.
Robertson, G. A. (1907), Merchants' Ice & Cold Storage Company, Brook and Main streets, Louisville, Ky.
*Rodgers, Charles W. (1911), Independent Ice Company, Wilmington, N. C.
Roelker, H. B. (1904), (Vice-President 1905, Director 1906-'08), 41 Maiden lane, New York, N. Y.
§Roos, Frank J. (1906), Foote Bros. Gear & Machine Company, 214 North Carpenter street, Chicago, Ill.
*Rose, Clarence E. (1911), 500 East Sixth street, Little Rock, Ark.
Rosener, Leland S. (1910), 1129 Merchants' Exchange building, San Francisco, Cal.
*Ross, William H. (1904), (Secretary), 154 Nassau street, New York, N. Y.
*Roy, L. A. (1911), Rector building, Chicago, Ill.
*Ruddick, John A. (1906), Dairy and Cold Storage Commissioner, Ottawa, Canada.
Ruemmeli, Albert (1909), (Vice-President 1911-'12), Ruemmeli-Dawley Manufacturing Company, 3900 Chouteau avenue, St. Louis, Mo.
§Sandholt, Walter W. (1909), 3965 Wilda Vale avenue, Oakland, Cal.
Schadek, E. W. (1905), Ruemmeli-Dawley Manufacturing Company, 3900 Chouteau avenue, St. Louis, Mo.
Schantz, K. W. (1912), Wegener Machine Company, Perry and Mississippi streets, Buffalo, N. Y.
Schmidt, Louis M. (1904), 84 West Main street, New Britain, Conn.
§Schulte, Charles F. (1911), 2723 Bennett court, St. Louis, Mo.
*Seigle, Joseph (1911), 417 East Court street, Cincinnati, Ohio.
*Serrill, Horace P. (1905), 411 North American street, Philadelphia, Pa.
*Sethman, George H. (1909), 647 Williams street, Denver, Col.
Shipley, Samuel J. (1904), 90 West street, New York, N. Y.
Shipley, Thomas (1904),(Director 1905-'11, President 1912, Director) York Manufacturing Company, York, Pa.
Shipley, William S. (1906), 90 West street, New York, N. Y.
*Smith, Guy B. (1907), 306 St. James place, Brooklyn, N. Y.
*Sparks, John C. (1906), 30 Church street, New York, N. Y.
§Spinka, Jaroslav (1912), Ruemmeli-Dawley Manufacturing Company, 3900 Chouteau avenue, St. Louis, Mo.
Starr, John E. (1904), (President 1905, Vice-President 1906-'07, Director 1908), 90 West street, New York, N. Y.
*Stephens, Jr., L. H. (1907), St. Louis Refrigerating & Cold Storage Company, Lewis and O'Fallon streets, St. Louis, Mo.
Sterrett, A. W. (1909), Pacific Cold Storage Company, Tacoma, Wash.
*Stevenson, Oscar (1912), 313 West Seventh street, Chester, Pa.
*Stevenson, S. P. (1907), 1500 West Fourth street, Chester, Pa.

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*Stockman, O. S. (1909), Armstrong Cork Company, Union Bank Building, Pittsburg, Pa.
*Stone, Junius H. (1906), (Director), Crown Cork & Seal Company, Palamos, Spain.
Stratton, Harrison D. (1908), 2610 Callowhill street, Philadelphia, Pa.
Strickler, A. B. (1906), York Manufacturing Company, York, Pa.
Tait, Roderick H. (1907), (President 1910), Liggett building, St. Louis, Mo.
Takahashi, Torata (1911), Teikoku Reizo Kabushiki Kwaisha, 12 Akashicho, Tsukiji, Tokyo, Japan.
Taylor, John R. (1907), 613 South Ervay street, Dallas, Tex.
Taylor, Walter A. (1907), P. O. Box 461, Hammond, La.
Thompson, Edgar W. (1905), Thompson & Gidley, P. O. Box, 260, Bombay, India.
*Tihotsky, Constantin (1911), 77 Sergierskay street, St. Petersburg, Russia.
*Tinker, Henry W. (1905), 41 Richmond street, Boston, Mass.
Torrance, Jr., Henry (1904), (Director 1905-'07, Vice-President), 50 Church street, New York, N. Y.
Trautwein, Alfred P. (1904), Carbondale Machine Company, Carbondale, Pa.
*Turner, Charles L. (1905), 411 North American street, Philadelphia, Pa.
Uchimura, Tatsujiro (1908), 10 Yariyacho, Kiobashiku, Tokyo, Japan.
Vesterdahl, Karl (1904), (Vice-President 1908-'09), 90 West street, New York, N. Y.
Vilter, Theodore O. (1908), (Director), 872 Clinton street, Milwaukee, Wis.
Vogt, Henry (1904), Henry Vogt Machine Company, Louisville, Ky.
Vollmann, Carl W. (1904), Linde Canadian Refrigerating Company, 37 St. Peter street, Montreal, Can.
Von Weise, Louis B. (1911), 3003 North Broadway, St. Louis, Mo.
Voorhees, Gardner T. (1904), (Director 1910-'12), Engineers' Club, 32 West Fortieth street, New York, N. Y.
Voss, Bernhard (1904), 427 East One Hundred and Fortieth street, New York, N. Y.
Wait, John C. (1904), (Director 1908-'10), Woolworth building, New York, N. Y.
Waite, Nelson J. (1907), Sheriff Street Market & Storage Company, Cleveland, Ohio.
§Wallber, H. C. (1912), Vilter Manufacturing Company, Milwaukee, Wis.
Walter, Bruce (1907), 6823 Thomas boulevard, Pittsburgh, Pa.
§Warner, Irving (1906), Charles Warner Company, Wilmington, Del.
*Webber, W. J. (1910), Cochrane Chemical Company, 40 Central street, Boston, Mass.
§Weddell, George O. (1911), York Manufacturing Company, York, Pa.
Wegemann, Karl (1904), (Director 1908-'10), Ice Cream Construction Company, 90 West street, New York, N. Y.
§Weisenbach, Frederick A. (1912), 140 North Tenth street, Philadelphia, Pa.
Wells, George E. (1911), Anheuser-Busch Brewing Association, St. Louis, Mo.
*Werliin, L. (1905), 2815 Gray's Ferry road, Philadelphia, Pa.
Westerlin, J. M. (1912), Westerlin & Campbell Company, 26 North Clinton street, Chicago, Ill.

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*Whittemore, Clinton L. (1911), 48 Gay building, Third and Pine streets, St. Louis, Mo.

*Whitten, William M. (1907), Armstrong Cork Company, 50 Church street, New York, N. Y.

*Widmann, F. (1906), Wainwright building, St. Louis, Mo.

Wildridge, Richard (1912), 76 Pitt street, Sydney, Australia.

Williams, E. T. (1911), Westerberg & Williams, Woolworth building, New York, N. Y.

Williams, Llewellyn (1904), (Director 1907-'09), United Fruit Company, 131 State street, Boston, Mass.

Winborg, Abel (1906), 428 Park street, York, Pa.

§Wittemann, Rudolph W. (1905), Wittemann Brothers, 41 Ferris street, Brooklyn, N. Y.

Wittenmeier, Fred (1910), 470 West Erie street, Chicago, Ill.

§Wolf, Carl B. (1906), 511 Denckla building, Eleventh and Market streets, Philadelphia, Pa.

Wolf, Fred W. (1904), 7341 North Ashland boulevard, Chicago, Ill.

Wolf, Otto C. (1904), 511 Denckla building, Eleventh and Market streets, Philadelphia, Pa.

Woodcock, Willard J. (1905), 13 Cambridge place, Brooklyn, N. Y.

Woods, Arthur R. T. (1905), The Red Cottage, West Hill, Harrow, Middlesex, England.

*Wright, George W. (1907), Baltimore Refrigerating & Heating Company, 426 South Eutaw street, Baltimore, Md.

Wuertenbaecher, John J. (1908), 3315 Russell avenue, St. Louis, Mo.

Yeakley, L. F. (1912), Twenty-sixth street and Susquehanna avenue, Philadelphia, Pa.

Young, Conrad H. (1906), Armstrong Cork Company, Union Bank building, Pittsburgh, Pa.

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* Associate Member. § Junior Member.

Names without reference marks are Members.

Figures in parentheses, as (1904), immediately following the name, denote year of admission.

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IN MEMORIAM

	Born	Died
Blethen, Henry,	February 27, 1857	April 24, 1909
Becker, Victor H.,	June 6, 1852	November 15, 1912
Boyer, Francis H.,	September 6, 1845	February 21, 1909
Collins, John Glenn,	July 28, 1854	April 19, 1908
Gould, Ovid M.,	April 23, 1838	February 21, 1911
Hier, Frank T.,	July 6, 1859	February 2, 1912
Huntley, Clifford E.,	December 14, 1868	November 14, 1912
King, Rockwell,	1853	July 27, 1905
Maschwitz, Carlos.	May 7, 1862	1911
Siebert, Alfred,	1853	July 20, 1909
Smart, John M.,	August 8, 1866	April 14, 1912
Smith, Edmund J.,	October 21, 1856	September 17, 1906
Tough, L. M.,	1846	April 15, 1911
White, Frank H.,	September 22, 1874	May 26, 1907
Willis, James,	April 30, 1845	March 29, 1910

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